Penetrating Spinal Cord Injury

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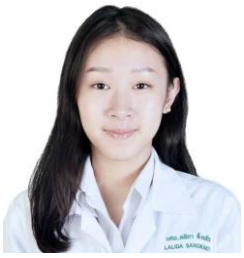
Patcharaporn Teerarochanapong  5929640265	Lalida Sangkakit  5929694037

Case: 2 year old Thai boy from Pathum Thani

CC: Gunshot wound 1 hour PTA

Preparation:

- Prehospital phase: The patient was brought to the hospital by his family members (23.09)
- Hospital phase: The trauma team and ER was prepared with standard precaution, face mask and water-impervious gloves.

Triage: The patient was categorized as emergent. Trauma team and neurosurgery team were notified.

Primary survey:

- Quick assessment: The patient was drowsy but was responsive and he had a clear voice while crying. An unclear non-patient airway or inadequate cerebral perfusion was not suspected.

Airway maintenance with restriction of cervical spine motion:

- No signs of airway obstruction and severe airway injury
- Inspection: drowsy, no cyanosis, no agitation, no use of accessory muscles, no noisy breathing, no stridor, no hoarseness, no maxillofacial injuries, no injury to neck or larynx.
- Palpation: no trachea and larynx fracture, no subcutaneous emphysema, c-spine tenderness not able to be tested
- Oxygen mask with bag flow 10 liters per minute was administered with pulse oximetry monitoring
- C-spine was maintained in neutral position with the manual inline procedure during airway control

Breathing and ventilation:

- Inspection: full exposure of neck and chest, RR 24, symmetrical chest movement, no open chest wound, no venous distention, no flail chest, pulse oximeter 98% at room air → on oxygen mask with bag 10 LPM → 100%. Active bleeding from gunshot wounds; 1 laceration wound at occiput 2x3 cm, 4 at lower back, 1x1 cm each
- Palpation: no subcutaneous emphysema, trachea in midline
- Percussion: resonant on percussion both lungs
- Auscultation: clear and equal breath sound both lungs
- There are no signs of tension pneumothorax, open pneumothorax or massive hemothorax upon initial examination.

Circulation and hemorrhagic control:

- GA: Looked drowsy, no agitation, no behavioral change, no pallor
- V/S: BP 134/60 mmHg, PR: 101/min, full and regular pulse all extremities (2+)
- Skin: Warm and moist
- RLS 300 mL IV drip in 15 minutes
- G/M PRC 2U, FFP 1 U

Disability:

Rapid neurological evaluation

- E3V5M6
- Pupils Rt 3mm RTL, Lt 3mm RTL
- No lateralization
- Motor power: Upper extremities at grade V/V
  Lower extremities grade I/V
- Sensation: Intact pain and light tough from C1-T4
  Loss of pain and light tough below T4
- Deep tendon reflex: 0
- Muscle tone: hypotonia

Exposure and environmental control

- Patient was undressed to assess wounds and bleeding site
- Blanket was given to prevent hypothermia
- Log roll maneuver:
  - One laceration wound at occiput (2x3 cm) and four gunshot wound at lower back (1x1 cm each)
  - Cannot assess C-spine tenderness or spine tenderness
  - No stepping along spinal line
  - PR: loose sphincter tone, absent anal wink

Pictures were posted with parental consent

Adjunct to primary survey:

- Pulse oximeter: oxygen saturation 100% on mask with bag oxygen flow 5 liters per minute
- ECG: normal sinus rhythm rate 100
- Foley catheter: clear yellow urine
- Nasogastric tube: not done
- eFAST: negative at 23.10, no intra-abdominal bleeding, no lung sliding
- Film chest x-ray portable: no trachea shift, no pneumothorax, no hemothorax, five bullets seen at back (1 bullet suspected to be in the intrathoracic cavity)

Secondary survey
A: No known food or drug allergy
M: No known medication
P: No past illness, past tetanus unknown
L: Last meal unknown

E: 22.00 The patient was playing with this father's shotgun (ปืนลูกซองไทยประดิษฐ์ เบอร์ 12). The patient's father saw the incident, therefore, attempted to retrieve the shotgun from the patient but the shotgun was accidentally fired and the bullets hit the patient's back. Soot deposition is present around the edge of the gunshot wounds at the back. The patient was conscious throughout the entire incident. However, had less movement at lower extremities and only felt pain at the laceration wound at occiput.

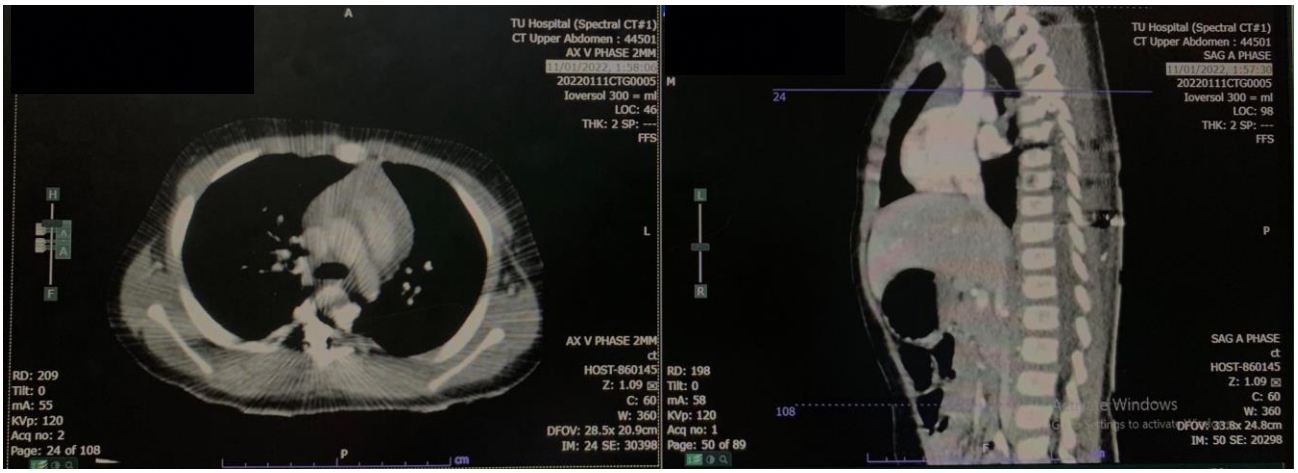
Head to toe examination:

- Vital sign: BP 134/60 mmHg, PR 101/min, RR 24/min, BT , O2 saturation 100% on oxygen mask with bag flow 10 liters per minute
- Anthropometrics: BW 15 kg, height not recorded
- General appearance: Look drowsy
- HEENT: No palpable depressed fracture, no hematoma, no facial fracture seen, C-spine tenderness cannot be evaluated, no pale conjunctiva, anicteric sclera
- RS: no flat or engorged neck veins, trachea in midline, no subcutaneous emphysema, clear and equal breath sound both lungs, no stridor, no wheezing, no hoarseness
- CVS: full and equal pulse all extremities, capillary refill < 2 seconds, normal S1S2, no murmur
- Abdomen: soft, not tender, not distended, no guarding, no rigidity
- Extremities: no deformity, full range of motion, no fractures
- Back: pressure dressing done at gunshot wound at occiput and back
- Pelvis: no tenderness
- Neuro:
    - E3V4M6
    - CN II: pupil 2 mm BRTL, RAPD negative. VA VF not evaluated
    - CN III, IV, VI: full EOM
    - CN V: normal facial sensation, no muscle of mastication weakness
    - CN VII: no facial palsy
    - CN XIII: no hearing loss
    - CN IX, X: normal gag reflex
    - CN XI: no weakness of trapezius muscle and SCM muscle
    - CN XII: no tongue deviation
    - Consciousness: Drowsy
    - Motor power: Upper extremities at grade V/V
      Lower extremities grade I/V
    - Sensation: Intact pain and light tough from C1-T4
      Loss of pain and light tough below T4
    - Deep tendon reflex: 0
    - Muscle tone: hypotonia
    - Beevor sign: cannot be evaluated
    - Babinski’s sign absent
    - Clonus negative
    - Bulbocavernosus reflex: positive
    - Proprioception: cannot be evaluated

- Genitalia: no bleeding per urethral meatus, no perineal ecchymosis, no high-riding prostate
- PR: loose sphincter tone, yellow feces

Adjunct to secondary survey:

- CBC: Hb 10.1 g/dL, Hct 31.2 %, WBC count 17900, neutrophil 49.6%, lymphocyte 39.1%, platelet count 402000
- BUN 13, Cr 0.28
- Electrolyte: NA 138, K 3.3, Cl 108, HCO3 21
- PTT 21.5, PT 12.4, INR 1.05, PTT ratio 0.85
- UA: clear pale yellow, specific gravity 1.027, RBC 3-5, WBC 10-20, squamous epithelial cell 1-2, nitrite negative
- CT chest and upper abdomen:
    - Lung parenchyma and airway
        - Normal lung volume
        - Patchy opacities and ground glass opacities at the posterior basal segment of RLL are seen.
        - Plate atelectasis involving apical and posterior segments of RUL is shown
        - Dependent atelectasis at posterior aspect of both lower lobes are observed
        - Trachea and both main bronchi are patent
    - No pleural effusion or pneumothorax
    - Thoracic vessels are patent
    - CT brain: no pathology seen
    - Chest wall, lower neck and bony structures: There are five retained bullets with small metallic fragments at multiple sites as follows -
        - Intramuscular later at right upper back adjacent to right scapula
        - Right sided spinal canal at T4 associated with small body fragments
        - Right sided back near the right posterior 7th intercostal space
        - Right posterior 8th intercostal space abutting the pleura
        - Intramuscular layer of right paramedian back
    - There are few crescent, intradural hyperdense lesions along both sides of the spinal canal from T4-T10 levels. Pressure effect to the spinal cord is also seen, more severe at T9 level. The rest of the bony structures and chest wall are intact.
    - **Fractured T4 (pedicle, facet, posterior body) fractured T7, bullet retained in spinal canal at T4 and T7
    - Patent hepatobiliary system, pancreas, spleen, adrenal glands, stomach, kidneys and abdominal vessels.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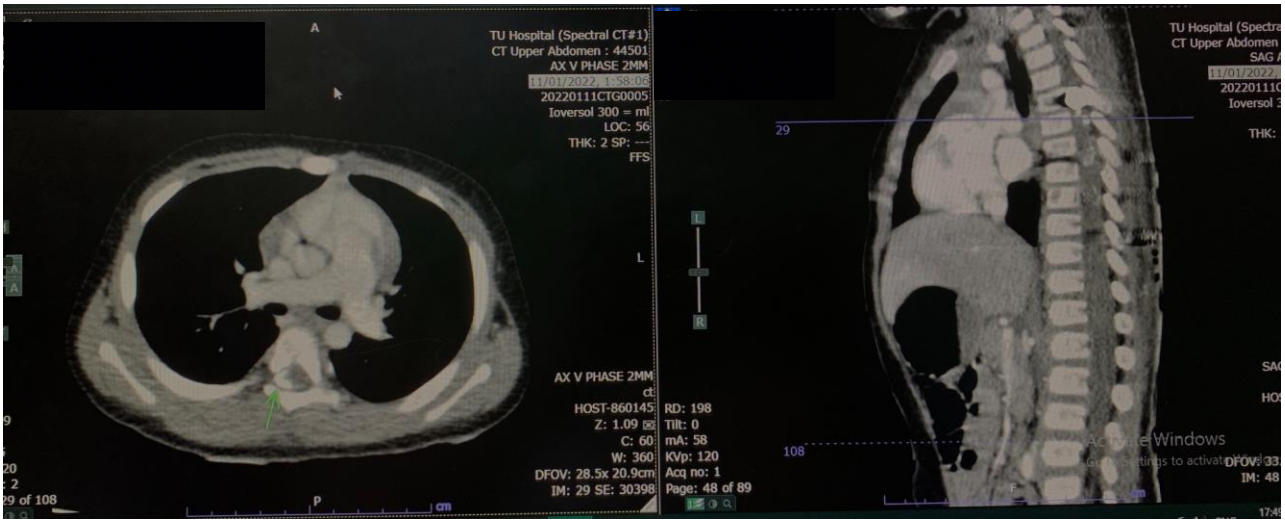
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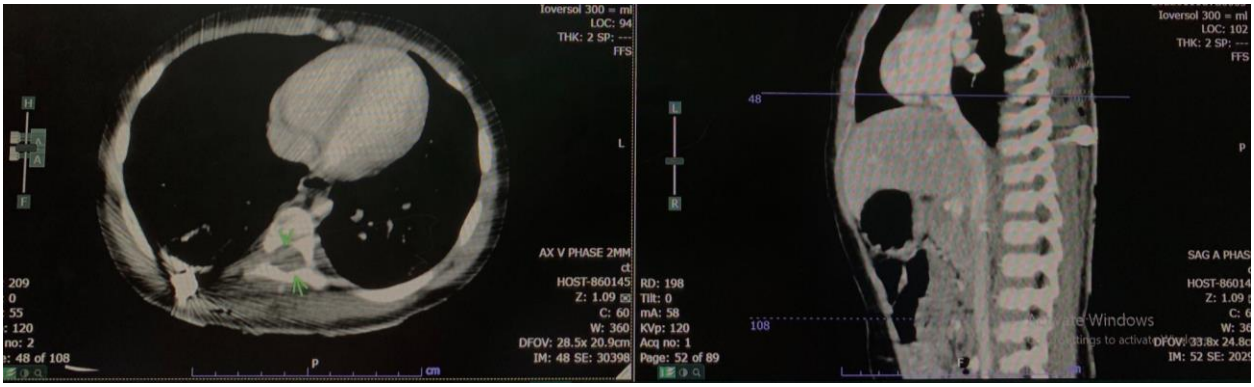
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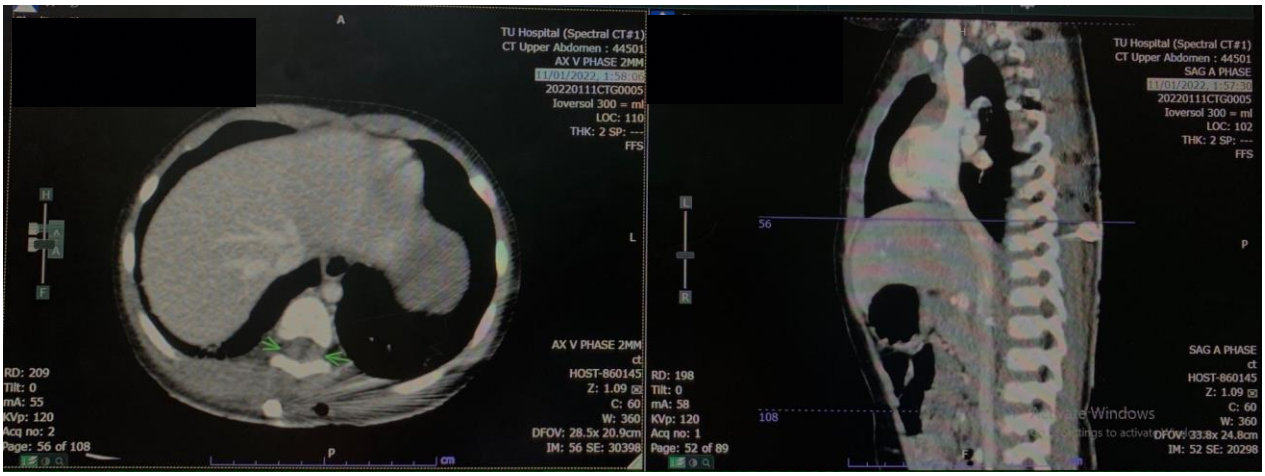
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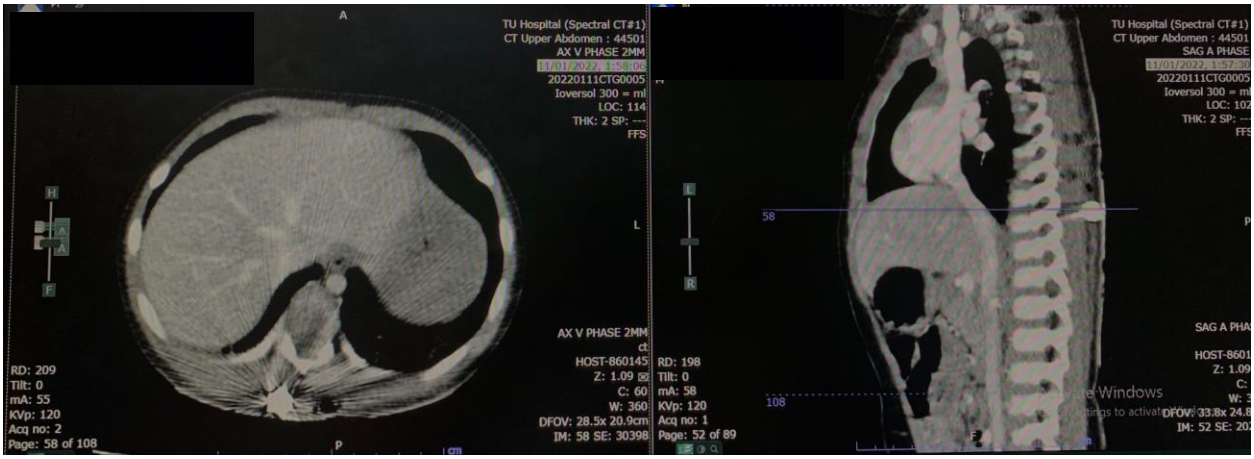
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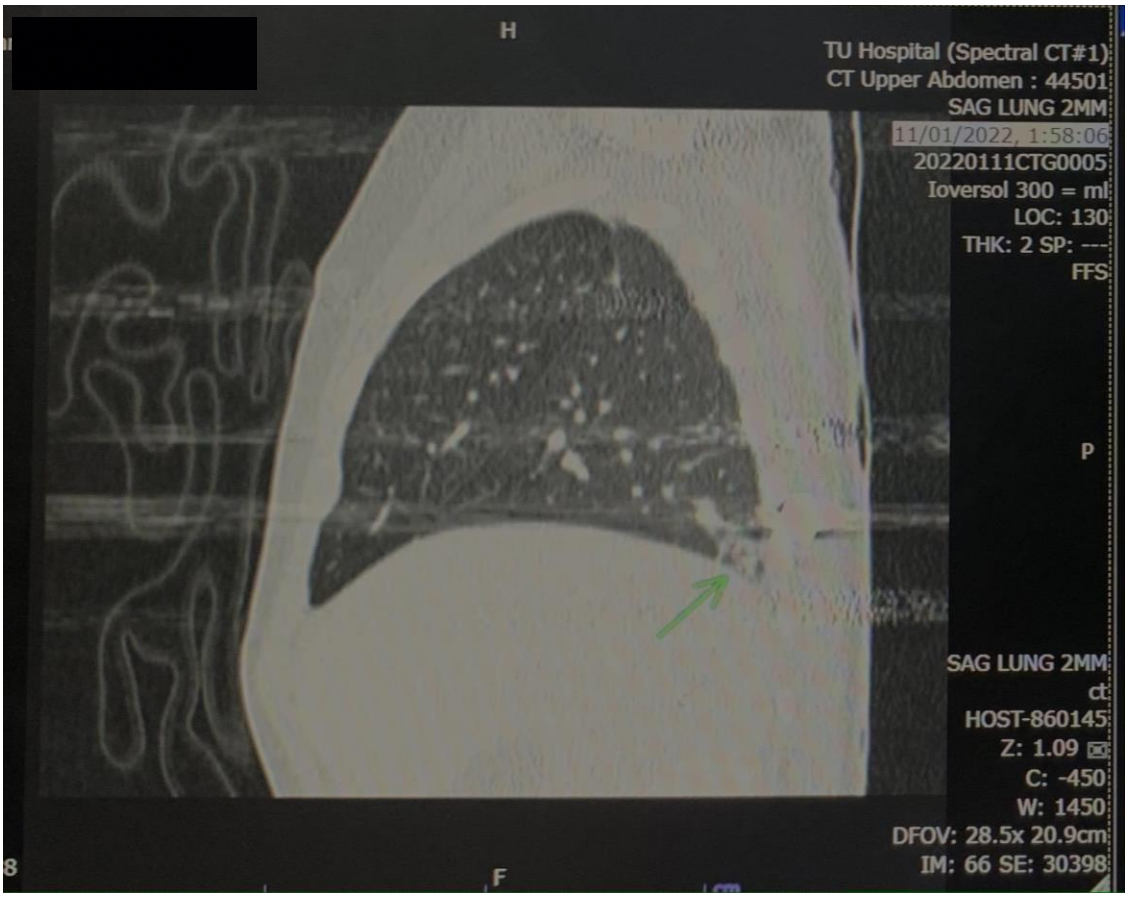
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Discussion of spinal cord injury and lesion localisation

During the initial presentation, it is difficult to distinguish if the patient has upper or lower motor neuron lesion since signs of upper motor neuron lesion may be absent at first. However, the spinal cord injury is suspected in this case because all of the lower extremity muscles are affected. The lower motor neuron lesion that would explain the patient's loss of motor power is the bilateral lower nerve root plexus injury, though possible, it is highly unlikely due to the mechanism of gunshot penetrating injury and bullet trajectories from buttock to upper back.

The physical examination findings reveal that the patient has grade II/V motor power at both lower extremities while the motor power of upper extremities is at least grade III/V, hence, the lesion should be below T1 level. The patient loses the pain sensation below the nipple line. Hence, the lesion should be from T4 level downwards. Since the lesion is suspected to be at the thoracic cord area, Beevor's sign would be helpful to specifically localize the lesion. Nevertheless, Beevor's sign was not examined in this case because the patient is a child and could not incorporate. In conclusion, the patient is likely to have thoracic spinal cord injury at T4 level.

Since we suspect that the patient has spinal cord injury, we have to further categorize if the patient has complete spinal cord injury, incomplete spinal cord injury or spinal shock. The patient does not have spinal shock because he still has intact motor function and bulbocavernosus reflex is present. The complete spinal cord injury is unlikely because he still has intact motor function. The patient is likely to have incomplete spinal cord injury because his motor function is still preserved. The most caudal injury segment with intact sensation bilaterally in this case is T4 level. The most caudal injury segment with normal motor sensation bilaterally is T1 level because it was observed that he could still do finger abduction. Neurological level of injury is T1 level because it is the most caudal segment with normal sensory and motor function on both sides. The zone of injury is 2-3 levels below neurological level of injury. Still, we have to consider the fact that motor function of the thoracic level was not carefully examined in this case. Hence, the determination of neurological level of injury in accordance with American Spinal Injury Association (ASIA) guideline might not be accurate. According to ASIA impairment scale, the patient has grade C spinal cord injury because the motor function is preserved below the level of injury but more than half of affected muscles have motor or less than grade III/V

Gunshot wound

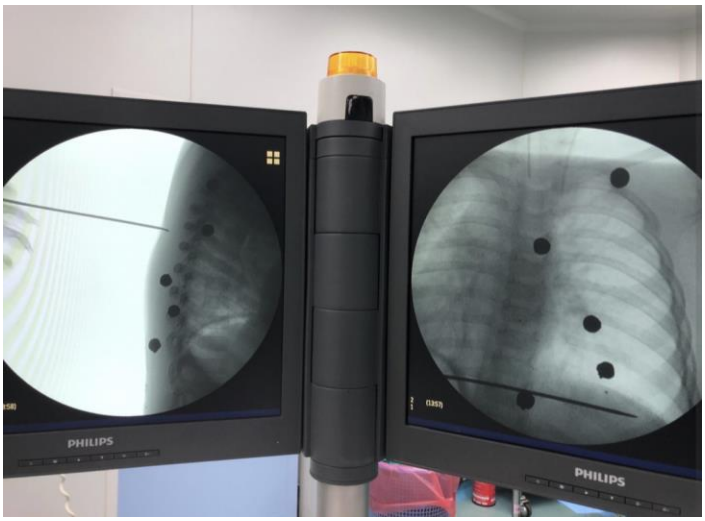
Further evaluation of the gunshot wounds present upon physical examination revealed four entry wounds with irregular borders at the patient's left back at the thoracoabdominal area, located approximately 10 centimeters above the left iliac crest. The sizes vary from one to two centimeters, with the wounds resembling a cookie cutter pattern. Another visible abrasion wound is seen, with a size of 3 centimeters, located at the right occipital area. It is suspected that the wound located on the patient's left lower thoracoabdomen is the entrance wound from a shotgun, as inferred by the multiple, irregular border characteristic of the wound itself in conjunction with the patient's history of having misfired a homemade shotgun. It is postulated that this is also an entrance wound because an abrasion ring or marginal abrasion is seen. Moreover, there is soot around the wound of the entrance with surrounding punctate abrasions which could not be wiped away, resembling powder tattooing. Since the abrasion on the patient's right suboccipital area does not contain characteristics of those of exit gunshot wounds (it is neither a stellate, crescent nor a slit shape), it is believed that the trajectory of the bullet entranced at the patient's left lower back, motioning upwards towards the patient's upper abdomen and chest, and possibly intracranial areas without any evidence of the exit wound. This trajectory path is suspected from the width of the abrasion ring being more prominent and thick at the left lateral and distal sides more than the right, medial, and proximal sides of the wound, indicating that the contact of the gun must have been angled from the left pointing upwards. Moreover, the fire range in this case is suspected to be within the close to intermediate range (variable from 1 to 60 cm) due to the presence of powder tattooing scattered across the patient's right back, trunk and a little over the right abdomen. Powder tattooing from a shotgun is also less dense than those of a handgun when produced at the same range.

Management

From the aforementioned information about this case, the patient is said to have a penetrating incomplete spinal cord injury, therefore, further supportive and definite management should be as follows:

- Antibiotics was given:
    - Ceftriaxone 100 mg/kg/day IV once daily
    - Cloxacillin 150 mg/kg/day IV every 8 hours
- Hemoculture was taken before administration of antibiotics
- Keep oxygen saturation > 92% on room air
- Soft diet, if well fed then plan off intravenous fluids
- Omeprazole 1 mg/kg/dose IV once daily, plan step down to oral form when patient is able to eat
- Keep urine output >1 ml/kg/hour

- In this patient, there is a role for decompression and bullet removal because from physical examination, the patient has incomplete spinal cord injury which is an indication for surgery. Moreover, from the imaging, there is evidence of bullet compression and direct penetrating injury to the cord at the level of T4, although spinal fracture initially was inconclusive. As a result, an operating room for laminectomy of T4 level with bullet removal with wound debridement was set the following morning. This patient also had no contraindication to proceeding towards an emergent operation. Even so, re-examination of the patient right before he entered the operating room revealed a motor power of grade 0 both lower extremities, indicating that he might have progressed to a complete cord injury. The role of fixation in this patient was not evident as he did not demonstrate any aspects of spinal instability such as malalignment or displacement of the vertebral columns. Intraoperative findings also revealed a defected dura at level of T4 with the retained bullet located at the right side compressing the spinal cord that has been deviated to the left side. After removal of the retained bullet, minimal CSF leakage was also detected. As a result, duraplasty was also performed with fat graft and Tisseal.
- This patient although had no indication for surgical removal of other retained bullets apart from the level of T4, bullet removal was completed at other sites as well due to considerations that the patient may have to undergo MRI scannings in the future, in conjunction with the fact that the visualized bullets were located rather superficially and were all easy to obtain with the benefits outweighing the risks.
- This patient did not receive administration of corticosteroids since the role of steroids in penetrating spinal cord injury is inconclusive and poses a risk of infection towards the patient, especially in this case where the wound was rather contaminated.
- Post operative order
    - Bed rest for at least three days
    - Acetazolamide 5 mg/kg/dose oral every 12 hours
    - Antioxidants with Vitamin C 50 mg oral per day and Zinc 3.3 mg/kg/day oral



Pictures were posted with parental consent

Bullets were identified under fluoroscopy and locations were marked with permanent markers as seen on the left image.

Post-operative day 1, the patient was alert and fully conscious, however, his motor power grade of both lower extremities improved to a grade of 1. He also still had decreased sensation at levels below T4. The surgical site wounds were not swollen, not erythematous, and not warm. He had one peak of low-grade fever at a body temperature of 37.8 degrees celsius.

Post-operative day 1

Pictures were posted with parental consent

Penetrating Spinal Cord Injury

In today's modern era, there has been a recent increase of gunshot injuries, which greatly introduced the role of neurosurgeons. In such trauma, one must always rule out spinal cord injuries isolating them from simple fractures or extradural lesions. There could be isolated spinal cord injuries, or even secondary spinal cord injury from bone transection or fractures. Management and classification can be segregated according to levels of the patient's presenting injury. Cervical cord injuries are the most common and are also the region with most complications [1]. This is because the vertebral artery passes through the transverse foramen, thus causing it to be prone to brainstem ischemia [1]. While the thoracic spine level is generally stronger due to multiple supporting structures allowing for maximal flexibility thus receives less impact from trauma and flexion/ extension injuries [1]. The lumbar spinal cord encompasses much larger bones due to it being weight bearing joints and needs a larger group of muscles for attachment, making the epidemiology a much lesser percentage regarding spinal trauma [1].

Spinal anatomy

The spine consists of 33 vertebrae; 7 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 4 coccygeal vertebrae [2]. The normal curve of spine is lordosis at the cervical and lumbar region, and kyphosis at thoracic and sacral region [2]. Between each level of the vertebrae contains the intervertebral disc, which is composed of annulus fibrosus and nucleus pulposus, acting as a shock absorber. According to Denis's theory, the vertebrae is divided into three columns; anterior, middle and posterior column. The anterior column starts from the anterior longitudinal ligament to the middle part of the vertebra. The middle column then continues on from the middle part of the vertebrae to the posterior longitudinal ligament. Lastly, the posterior column is all the structures posterior to the posterior longitudinal ligament [2]. The motion of the cervical spine is rotation, flexion, and extension. The upper cervical spine, C1-C2, plays an important role in stabilizing the occiput to the spine and enables the function of head rotation. From C1-C6, the vertebral artery passes through the transverse foramen. Thus, injury affecting this area can possibly cause brainstem ischemia [1]. The thoracic region is fairly stiff due to the articulation to the rib cage. The main motion of the thoracic region is rotation, and only a minimal degree of flexion and extension. Thus, flexion/extension injury to the thoracic region is greatly protected [1]. The upper thoracic has coronal orientation alignment, which can prevent anterior translation in this region, but is unable to prevent rotational force. The lower thoracic has sagittal orientation, which can strongly prevent rotational force, but not the anterior translation of the spine [1]. The lumbar spine contains the largest vertebra, as it has to bear massive weight. Thus, it is the most common site for pain [2]. Its motion is flexion and extension, with minimal rotation.

Spinal Cord Anatomy

The spinal cord functions as a transmitter of the nerve signals from the brain to the body. It consists of three layers; pia, arachnoid, and dura. The outer layer of the spinal cord has the characteristic of a dentate ligament, which allows it to adhere to the vertebra, therefore maximizing the stability of the spinal cord [1]. The spinal cord is around 14 millimeter in diameter, and it extends starting from the medulla oblongata, at C1 level, down to the conus medullaris, which is around the level of L1-L2. The conus medullaris is stabilized by filum terminale. There are 31 spinal nerves in total; 8 cervical, 12 thoracic, 5 lumbar, 5 sacral,and 1 coccygeal spinal nerves [1]. Since the average length of the spine is around 70 cm, and the spinal cord's length is around 45 cm, thus the level of spinal cord and the spine is unequal[1]. Generally, the cervical spinal cord will be at the level of the cervical spine. The thoracic spinal cord will be at the level of T1-T8. THe lumbar spinal cord will be at the level of T9-T11. Lastly, the sacral spinal cord will be at T12-L2. The white matter of the spinal cord is composed of 3 columns anterior, lateral, and posterior white columns. It houses numerous tracts, such as pyramidal tract, spinothalamic tract, fasciculus cuneatus, fasciculus, gracilis [2]. The gray matter consists of neurons, which is divided into posterior, anterior, and later horn. The posterior horn has sensory nuclei, while the anterior horn has motor nuclei, and the lateral horn has autonomic function [2].

Figure 1. Lateral view of whole spine [2]

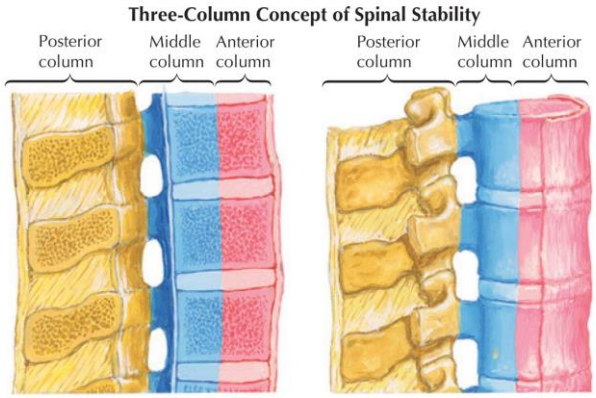


Figure 2. Three column concept of spinal stability[2]

Types of Injury

Penetrating spinal cord injuries can be classified by non-missile (knife, sharp objects, forks, scissors) and missile-penetrating spinal cord injury. Non-missile penetrating spinal cord injury generally occurs at the thoraco-cervical area where the patient's clinical condition may be extensive, varying from asymptomatic to a complete injury depending on whether neurovascular damage occurs [3]. Imaging modalities can be selected upon the case of use, such as X-ray to determine depths of secondary lung injury, or CT scan to see the extension of injury and involvement of adjacent organs [3].

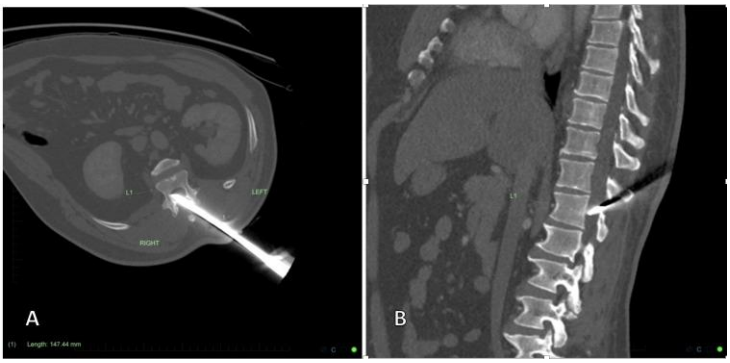


Figure 3. CT of a non-missile penetrating injury

Missile-penetrative spinal cord injuries are the third most common type of spinal cord injury [4]. It can be caused by a variety of methods, namely gunshot wounds. Generally, injuries to the thoracic level are the most common (48-64%), followed by cervical level(19-37%), and lumbosacral level (10-29%), apparent to the number of their anatomical levels [5]. The wounds created by firearms are generally stable yet the low and high velocity bullets can inflict considerable neurological damage as they move through tissues. The degree of damage caused by a bullet is generally understood to be dependent on the qualities of the bullet and the tissues it strikes. In addition, the location and resistance naturally occurring in such locations reflects the injury transferred to the body creating the “cavitation effect” [3]. Each and every step in management is thus extremely vital as it starts from the time of injury and extends beyond the rehabilitation period. Upon encountering the case, immediate immobilization, necessary care of open wounds, maintenance of hemodynamic stability and early transfer to a higher center are all required. The standard ATLS protocol (ABCDE) should be used upon resuscitation of the patient. Figure 4 demonstrates a brief summary for the general management of a penetrating spinal injury case.

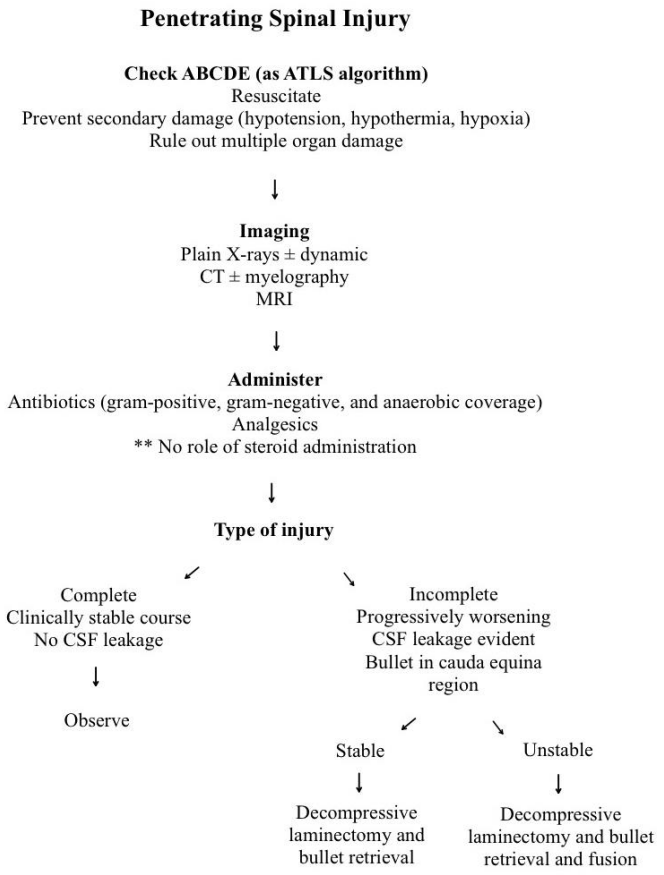


Figure 4. Overall management of a case with penetrating spinal injury

During the foreign bodies such as bullets. Recently, CT scans and MRIs have had increased importance in their roles as well. Overall, CT scan is roughly the most suitable form of imaging, as it well delineates the bony anatomy, thus analyzing the stability of the bone more easily and the entry/exit sites of the bullets that entered the body.

Surgical decompression is indicated in the following conditions:

1. Injury to the cauda equina
2. Neurologic deterioration that may suggest spinal epidural hematoma
3. Compression of a nerve root
4. CSF leakage with impending risk of meningitis
5. Spinal instability
6. To remove a copper jacketed bullet
7. Incomplete cord injury
8. Debridement: to reduce the risk of infection in the case where tissue damage is vast
9. Vascular injuries
10. Surgery for late complications i.e. migrating bullet, lead toxicity, post-operative late spinal instability

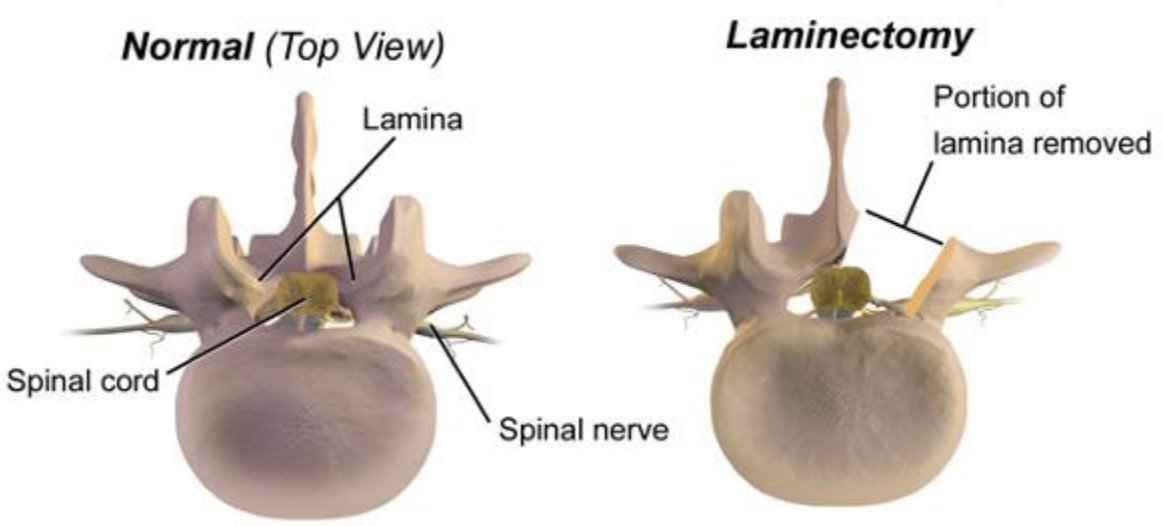


Figure 5. Decompressive laminectomy is done in cases with surgical indications, as listed below

In recent literature reviews regarding this matter, decompressive laminectomy is necessary if a surgical indication is present. In incomplete cord injury cases where there is no CSF leakage, exploration of the wound is not recommended until conservative management is attempted with adequate antibiotic coverage. Delayed surgery may be an option after infection has subsided.

In addition, the role of bullet retrieval operations may not alway be necessary unless patients [5]:

1. Have clinical deterioration (e.g. GCS score drop)
2. Have progression of the bullet pathways migration in the spinal canal
3. Dura fluid leakage
4. Have presenting risk factors for meningitis
5. Show signs of copper and lead toxicity

Newer research shows that removal of the bullet (or known as the foreign body) does not always improve the patient's status [5]. There are contradictory case reports seen in present literature.

In terms of medication, the role of corticosteroids in penetrating spinal cord injury is fairly controversial. Originally, it is recommended in cases with indirect blunt spinal injury within the first eight hours of the incident. However, recent reviews [6,7] have diverted attention to the risks of administering these medications. It is believed that the risk of compromise in immunity and probable infection is much greater than the benefits of giving steroids. As such, corticosteroids play no role in modern management of penetrating spinal cord injury.

Complications from Penetrative Spinal Cord Injuries

Penetrative spinal cord injuries, especially those occurring on higher levels of the spine, can especially cause delayed complications. Delayed cervical instability occurs in those who are affected but have not been recognized and to be on 20 days after the injury.[5] This may be delayed due to the pathology itself or due to delayed recognition. Instability in these types of injury may arise from a variety of reasons for instance radiologic imaging was evaluated inadequately, such as incomplete view of all cervical spinal levels up until the C7-T1 junction, motion artifacts, and incorrect positioning. Some abnormalities may be missed despite adequate imaging, including overlooked fracture or subluxation. Spasm of cervical muscles may contribute to seemingly slight reduction of injury initially. In cases where there is neurologic deficit, persistent pain, significant degenerative changes, subluxations less than 3 mm, or when surgery is an option, further imaging such as repeat x-rays should be considered.

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