Penetrating Brain Injuries PBI
(Civilian population)

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• Definitions of terms (missiles or non-missile, ballistics, etc.)
• Epidemiology
• Differences between PBI and blunt TBI
• Pathogenesis (anatomical structures involved, velocity of projectile, etc.)
• Missile vs. Non missile PBI
• Case presentations, medical and surgical management
• Outcome
Definition

- **Penetrating trauma**: an injury that occurs when object pierces the skin & enters a tissue of body, creating an open wound

- **Penetrating head injury** (or open head injury): there is a breach of coverings of brain (meninges) with high chance of damaging neurovascular tissues

- All TBI which are not the result of a blunt mechanism is classified under PBI
Definition

**Missile V.S Non missile PHI**

*speed matters!*

- **Non missile PHI**: speed of projectile < 100m/sec, e.g. stab wound
- **Missile PHI**: speed of projectile > 100m/sec e.g. gun shot
- **Differences in pathophysiology** in terms of underlying damage
- **Differences in prognosis**—majority of non-missile PBI survive, while majority of missile PBI die, or are left with significant disabilities
Definitions

- **Ballistics** = study of dynamics of projectile
- **Ballistics properties**: kinetic energy, mass, velocity, shape, etc.
- **Wound ballistics** = is the study of projectile's act in tissue, e.g., in the brain, shock waves, vacuum effect, etc.
\[ E = \frac{1}{2} M(VI^2 - VR^2) \]

- \( E \) = wounding Energy of projectile
- \( M \) = projectile mass (weight)
- \( VI \) = impact velocity
- \( VR \) = residual velocity, if the projectile has a perforating mode

Note: Small fire-arms in civilian GSWHs follow conventional ballistic rules of wounding energy, when Velocity of projectile is less than 700m/sec (if more than that, then formula will change)
Wounding energy (if \( V \) more than 700m/sec), depends on power,

\[
P = MV^3
\]

- \( P \) = power of projectile
- \( M \) = mass
- \( V \) = velocity

Note:

Many of the victims in the vicinity of cased, or an improvised explosive device (IED) will incur injuries by fragments with velocity of greater than 700m/sec and low ballistic coefficient
Epidemiology of PBI

- Injury is the 4\textsuperscript{th} leading cause of mortality, under age 45
- 200-400 TBI admission / 100,000 population (varies in different countries)
- Majority (over 90\%) are blunt head trauma
- **Penetrating Brain injury far less common than blunt TBI**
- In certain densely populated communities (Baltimore-Maryland, Bronx-NY), up to a third of severe TBI could be due to GSW in young male, with very high mortality
- **PBI caused by non missile objects represent a rare pathology** among civilians & prognosis is much better than missile PBI
Epidemiology of PBI

• Male > than female, (specially with GSW)
• Homicide, suicide, accidents, etc.
• PBI caries worse prognosis, esp. when associated with missile injury
• PBI are mostly caused by high velocity objects which results in more complex injury & higher mortality
• More chance of infection, as compared to closed head injuries
• Damage to blood vessel causing intracranial hemorrhage, ischemia, brain swelling, high ICP & its consequences
Penetrating objects
many variety

- Metals: nails, knife, rods, gun shots
- Organic matters: pieces of wood, pencil, etc
Factors determining the extend of injury

- **Low velocity projectile**, low kinetic energy, minimal shock waves. E.g. knife (speed <100m/sec) weak points of entry of skull
- **High velocity projectile**, high kinetic energy, high shock waves e.g. Gun (anywhere on the skull)
- **Nature of projectile**
- **Point of entry & angle of projectile**
- **Characteristics of intervening tissues** (skull, muscle, mucosa, etc.)
- **Anatomic & neurovascular structure of the passage**
Pathophysiology of high velocity projectile PBI (GSW)

• Primary injury:
  - DIRECT: 1- soft tissue injury.
    2- bone fracture ➔ comminuted.
    3- Cerebral injury in the path..
  - Coup + countercoup from missile impact
  - Shock waves (sonic)
  - temporary cavity formation.
• Secondary Injury......High ICP...
Shock wave & cavitation effect with GSW

- Direct blow, and damaging whatever it is on its path
- Shock waves, temporary vacuum effect, stretching, cavitation, deformity of tissue, further damage
Cavitation effect with GSW
Experiment with gelatin. Longitudinal shock waves, and temporary cavity, produced by the projectile, generating pressure waves as it enters a cube of gelatin.
Gunshot wound to brain, & shock wave effect (damage is beyond just the bullet tract !)
Translation of kinetic energy into tissue damage

- Is brought about by the tremendous amount of crushing pressure exerted on the brain parenchyma
- *Juxtamissile pressure* affects the brain tissue immediately in the path of a projectile and may be in the **thousands of atmospheres**
- *Longitudinal strong shock waves* start immediately after impact of the projectile with brain tissue, and travel in spheres ahead of projectile with velocities in excess of 1460 m/sec
- *Shock wave* last up to 10 µsec and measure up to 80 atm
- *Ordinary pressure waves* measuring up to 20-30 atm are generated as the projectile transfers its kinetic energy to the surrounding brain tissue and produces a temporary cavity. The negative pressure generated by the temporary cavity can suck contaminated material into the cavity (in addition to initial crushing effect)
Factors important in terminal ballistics

- Penetration
- Tissue density
- Fragmentation
- Detonation
- Shape of the charge
- Blast overpressure
- Combustion
- Incendiary effect (fire bomb effect)
ER management

• **Primary survey** & stabilization: *Airway, Breathing* (intubation per indication), cervical spine, *Circulation*, external hemorrhage

• **Inspection of wound**, after resuscitation: thorough inspection of scalp (powder burn, CSF leak, brain material exude!). Carefully remove collar, inspect the neck, all orifices should be checked.

• **GCS** should be noted, as well as clinical indication of raised ICP

• **Complete examination** of other organ systems

• Detailed medical history from the family & friends

• **Labs:** CBC, electrolytes, ABG, coagulation profile

• Type, & cross match,

• Alcohol & drug screen

• Transfer to radiology for imaging, CT, CTA, angiography, if indicated

• ICU, or O.R. depending on imaging
Antibiotic coverage

• Infection more than closed TBI: entrance of foreign bodies, hair, fragments, etc.
• Importance of meticulous debridement
• More infection if Para nasal sinuses penetrated, if CSF leak, or trajectory passing ventricles
• Military, pre-antibiotic era 60% (with use of AB, 4-11%, & civilian, 1-5%)
• Staph. Aureus, the most common bacteria, & Gram negative bacteria, etc.
• Coverage: broad spectrum, cephalosporins, metronidazole, vancomycin, 5-7 days (some use up to 2 weeks)
Seizure

- Seizure more common with PBI than closed TBI
- 30-50% of patients develop seizure
- 10% within 1st week, 80% during 1st 2 years
- Up to 18% may not have seizure until to 5 or more years after PBI
- BTF recommends seizure prophylaxis only for the 1st week, unless patients develop seizure, then should be treated accordingly
Imaging

• Plain skull & neck x-ray
• CT
• CTA (or catheter angio), if trajectory near:
  sylvien fissure, supra-clinoid carotid, cavernous
  sinus, vertebro-basilar vessels, or major dural
  venous sinuses

Vascular injuries: dissections, occlusion, delayed
pseudo-aneurysms, CCF
Surgical Rx

• Most of surgical Rx should be done in OR setting, (unless for minor wound closure in ER)
  • Do not attempt to remove visible foreign body in ER !!
  • Surgical debridement & removal of devitalized tissue in OR
  • Removal of mass lesion such as hematoma
  • If retained fragments are deep in vital area of brain, we do not attempt to remove them all
  • Close follow up for possible infection
Case presentations,
Gradual increase in speed !!

• Organic matter (wood) through orbit
• Sab wounds
• Nail gun wounds
• Gun shot wounds
Non missile penetrating *orbito-cranial injuries* has been reported with varieties of different objects: metals, wood, synthetic materials, etc. etc. *Wooden penetrating objects, an uncommon injury*
Orbito-cranial penetrating injury

• There has been report of various penetrating objects into the cranial cavity through the orbit
• These may be metal, glass, synthetic materials, or pieces of wood
• We report two cases of penetrating wooden objects into the cranial cavity entering from the eye, to the superior orbital fissure & cranium
• Management strategies is discussed
• 1st, a review of anatomy
Vulnerable anatomic regions of skull susceptible for penetrating injury with low velocity projectile

- **Orbital roof** (preferred, weak entrance for frontal lobotomy for P4 Freeman 1948)
- Special anatomic shape of orbit
- Temporal squama
- Cribriform plate
Special Anatomic structural characteristics of orbit

- Horizontal pyramid on a postero medial axis
- This shape tends to deflect objects entering to orbit towards the apex, where the superior orbital fissure & optic foramen may provide an easy passage into the intracranial space
Case#1
Male, age 20, fall off the bicycle on the country road, penetrating wound into inner cantus, note CSF leak. GCS 12, agitated, was intubated. Afferent pupillary defect, vision could not be tested.
Swollen, eye proptosis. Low density, ? Air bobble into superior orbital fissure (note incidental remote head injury sequella)
More refined cuts, with sagittal reconstruction, again, tract of foreign body?
No vascular injury
Ptyrional, intra/ extradural approach to extract all the pieces of wood
Extracted pieces of woods (cut end of cane wood on the sides of country rood) & 2 months PO, CT, small Rt posterior orbitotomy site, after drilling of clinoid process
Bamboo-like grass wood
3 month post injury

- Rt optic atrophy, no light perception
- Rt concentual pupilary light reflex present
- Lt light reflex present
- Rt VI nerve palsy
Case # 2
17 years old autistic, fall off the bicycle in a country road. Small wound into superior eyelid, dilated pupil, with proptotic congested eye, with limitation of extra-ocular movements. It was difficult to assess vision. He had to have lateral canthotomy to reduce intra-ocular pressure.
This is day #5 post-injury
Is this look like Orbital Apex Syndrome?
  Yes

- Pain
- Swelling, proptosis, congestion
- Ophthalmoplegia
- Decrease, or loss of vision
- Symptomatology related to specific ethology
Ethiologies of Orbital Apex Syndrome (OAS)

• **Inflammatory**: sarcoidosis, Lupus E., orbital inflammatory pseudo tumor, thyroid orbitopathy, etc
• **Infectious**: Fungus, bacteria, spirochetes, etc
• **Neoplastic**: head & neck T., neuronal T. Mets, hematologic
• **Iatrogenic (traumatic)**: sino-nasal surgery, orbito-facial surgery
• **Accidental (traumatic)**: penetrating & non-penetrationing
• **Vascular**: Aneurysm, CC-fistula, cavernous thrombosis, etc
• **Others** - mucocele

Re: S.Yeh, Current Opinion Ophthal. 2004
DDx: Cavernous sinus syndrome

- **Symptomatology**: Ophthalmoplegia, proptosis, chemosis, Horner S., V. nerve sensory changes
- **Etiology**: Infectious or non infectious inflammatory process, vascular, traumatic, neoplastic
A

1. Pituitary Gland
2. Cavernous Sinus
3. Sphenoid Sinus
4. Internal Carotid Artery
Case # 2  CT, proptotic left eye, with hypodensity in superior orbital fissure,
CTA, intimate position of foreign body with the left cavernous sinus
MRA, left carotid intact
Should we attempt to remove it, & how !?

• Imaging characteristic of this foreign body highly suggestive of wood (organic matter)
• There is high chance of infection with retained wood
• Trans-orbital !? Too risky, with very congested eye
• Trans-cranial !?
AN ALTERNATIVE EXTRADURAL EXPOSURE TO THE ANTERIOR CLINOID PROCESS: THE SUPERIOR ORBITAL FISSURE AS A SURGICAL CORRIDOR

OBJECTIVE: Dolenc has pioneered the extradural approach to the anterior clinoid process (ACP) in approaching the cavernous sinus, clinoidal space, and orbital apex. A key step is the division of the frontotemporal dural fold (FTDF). Less experienced surgeons may not be as versatile in their three-dimensional understanding of the superior orbital fissure and thus may risk injury to its contents. Through our cadaveric and subsequent clinical experience, we have devised a modification of the approach that permits safer handling of the contents of the superior orbital fissure.

METHODS: In five consecutive injected cadaveric heads (10 sides), we performed on one side a traditional extradural exposure of the ACP. On the other side, we performed our alternative dissection. Instead of exposing the ACP from medial to lateral and dividing the frontotemporal dural fold along the assumed path of safety, we followed the edge of the lesser wing from lateral to medial, uncovered the superior orbital fissure, and peeled the outer layer of the cavernous sinus medial to the foramen rotundum along the greater wing, thus uncovering the inferolateral surface of the ACP. This allowed dural division under full visualization.

RESULTS: The alternative method proved easier and more reliable in every case. We applied this technical modification in seven patients with no complications. Specifically, there was no injury to the oculomotor, lacrimal, frontal, or trigeminal nerves or branches. We present detailed anatomic expositions of the injected specimens.

CONCLUSION: This technical modification of the extradural approach of Dolenc is a simple, safe, and valuable adjunct to the exposure of the ACP. We recommend its use particularly by relatively inexperienced surgeons.

KEY WORDS: Anterior clinoid process, Cranial base surgery, Dolenc approach, Superior orbital fissure
Fronto-Temporal exposure
dotted line, hidden anterior clinoid
Pterional craniotomy, extradural dissection, retracting & exposure of Fronto-Temporal Dural Fold (FTDF = a)
a=FTDF over ant. clinoid, b= SOF, c= greater wing, d= lesser wing of sphenoid
a = FTDF, b = SOF, c = greater wing, d = lesser wing, e = posterior periorbita
Anterior clinoid hidden behind FTDF (a)
Superior Orbital Fissure (SOF): a cleft of 3x 22 mm lying between the lesser & greater wing of sphenoid, & passage of communication between the orbital apex and the cavernous sinus.
Cadaveric dissection of cavernous sinus

Annulus of Zinn, with extraocular muscle attachments, & neuro-vascular structures passing through SOF
Neurovascular structure passing through SOF

1. Lacrimal nerve (branch of ophthalmic N)
2. Frontal nerve (a branch of ophthalmic nerve)
3. Superior ophthalmic vein
4. IV cranial nerve
5. Superior division of III nerve
6. Naso-ciliary nerve (a branch of ophthalmic nerve)
7. Inferior division of III nerve
8. VI nerve
Back to **Case # 2**  Left FT craniotomy, EVD to facilitate retraction
Case # 2 : After drilling of greater wing of sphenoid, via extradural approach, & small orbitotomy, object is visualized sitting in the superior orbital fissure
Yellowish accumulation around the wood grew mixed bacteria. F/U, Vision seemed to be very low, with relative afferent pupillary defect, & improved EOM few month later.

Extracted whole piece of wood, note pointed part!
Be vigilant with Penetrating orbital wounds

• Wounds sometimes may appear deceptively minor, or superficial
• Sometimes patients symptoms could be trivial, or underestimated by parents and/or care giver
• Serious sequellae will happen, if penetrating objects are under diagnosed & under treated
Inherent nature of wood as penetrating agent

- Porous, organic material provides a natural reservoir for microbial agents (bacteria, fungi, etc.)
- It is soft & can fragment with minimal forces
- Not easily detectible by X-ray
- On the CT, low density, sometimes could be mistaken for S/C emphysema, or pneumocephalus
- High rate of infection (up to 65% with 25% mortality), if not detected & extracted completely early enough
Treatment of orbito-cranial penetrating injuries

- A multidisciplinary approach in various disciplines
- Medical Rx - Antibiotic coverage
- Surgical extraction & repair (extra-Intracranial), specially if retained wood, since there would be high chance of delayed infection
- When the foreign body traverses orbit & into the cranium, necessity of trans cranial exposure (extradural & intradural)
Summary
penetrating orbito-cranial wood injury

• Orbito-cranial injury had been reported with various non-missile objects
• This injuries may cause significant ocular & cranial damage & sequella
• Penenaiting injury with wooden objects is uncommon
• Importance of extraction of all the wood particles to avoid delayed infection, foreign body reactive granuloma, etc.
Knife, stab wounds
Case# 3
This man was stabbed with knife, through left ethmoid sinus, presented with CSF leak. Needed craniectomy, & eventual cranioplasty. Recovery, with very little deficit!!
Case # 4

This man was stabbed over the superior sagittal sinus, luckily, It was removed safely in the OR, after completion of vascular studies! .
F/U CTA, no damage ! No sequellae
Case# 5 This man was brought into ER, with a knife on his skull. A brilliant MD tried to remove it in the ER! It broke! We had to take him to OR to remove the rest of the piece. No brain damage!
Case# 6 45 years old man, 8 months after an attack (without any medical consultation, initially) presented with seizure, and this was found in his right frontal lobe!?
Surgical exposure
3 months PO, doing well (on anti seizure medication)
Case # 7 Case of blunt penetrating trauma with hammer (unfaithful boyfriend !!!?) very little sequella after surgical repair !!!
Case# 8  P4 patient, self inflicted PHI with power drill
Nail guns

Powered by explosive cartridges or compressed air.
They are powerful (pressure as high as 8.5 Bar, which could penetrate even concrete, with speed as high as 427 m/sec (like missile).

**Suicide attempt, or accidental,**
Less likely homicide.
Case # 9  nail gun injury, GCS 15
What should be done with this one !?
Because of close proximity of the nail with important vascular structures, only head of nail was cut off!! F/U CT, and clinical stability
Case # 10
Another suicidal attempt, & delayed removal of nail one year later!
Improvement of Lt facial paresthesia, sensible improvement of III nerve palsy, (Remained with residual hemianopsia, and memory changes as preop)
Gun Shots

I- Small (light) arms (bore size less than 20 mm)
II- Artillery (bore size more than 20 mm)
Civilian Gun Shot Wounds

- Usually are hand guns, with small caliber less than 20mm, muzzle velocity 200-400m/sec
- Civil disorder
- Crime
- Suicide
- Accident
Missile PHI

- **Low velocity bullet (up to 300m/sec)**: damage is mainly due to crushing effect of its passage through tissue. Mostly non-military (civilian, small caliber). Most of civilian hand guns
- **High velocity bullet ( >300m/sec)**: In addition to crushing the tissue, it will set up *secondary shock waves* & *cavitation* that results in rapid pressure pulses, causing *devastating destruction* distant form the missile track. High velocity bullet wounds seen often in *military* arena
High velocity missiles

• Injury caused by laceration & crushing of underlying tissues
• Injury caused by, rotation & shock waves causing stretching of tissue leading to momentary cavitation & its after effects (damaging blood-brain barrier, swelling)
Pathophysiology

• Primary injury:
  - DIRECT: 1- soft tissue injury.
    2- bone fracture → comminuted.
    3- Cerebral injury in the path..
  - Coup + countercoup from missile impact
  - Shock waves (sonic)
  - temporary cavity formation.

• Secondary Injury……High ICP…
Outcome of GSW

**GCS** at presentation is the major determinant for long term outcome (349 cases)

- **9-15 GCS:**
  - Good outcome 43%
- **6-8 GCS:**
  - Good outcome 32%
- **3-5 GCS:**
  - Good outcome 0%

Gunshot wound to the Head. Contemp Neurosurgery 17:1-5 1995
GSW

• Gunshot wound account for majority of penetrating head injury.
• Gunshot wound are the most lethal type.
• Two third die at the seen.
• Half of the survivor will die the first day.
• Overall mortality is 90%.
High mortality with

- high velocity GS
- Multi lobar injury
- Bi-hemispheric injury
- Ventricular bleed
- Low GCS on arrival
Generally, majority of bi-hemispheric GSW victims do not survive
Grim prognosis Gun shots wounds

- 90% of civilians sustaining GSW die
- 2/3 die at the scene
- In 2000, 250 people sustained GSW in state of Maryland, 222 (89%) of them died at the scene, and 45 died in ER
- Only 10 patients were alive in ER, 8/10 underwent surgery
- Only 6 (2.4%) eventually made a favorable outcome

Re: Aarabi, Youman text of Neurosurgery, 2011
Management of GSW

• Initial asees and resus
  → A→B→C…..
  → GCS +Pupils

ENTRY/EXIT SITE
must be identified.

→ Treat increasing ICP.
→ Anticonvulsant.
→ Antibiotics (staph/strept/E.Coli/Klebs/Entero)
→ tetanus….
Surgery (ASAP)

- Debridement of devitalized.
- Removal of any mass lesions.
- Removal of ACCESSIBLE bone fragment.
- Bullet fragment.
- Obtaining Homeostasis.
- Watertight dural closure.
- Adequate closure of scalp
Post.op

• ICU treatment of sever head injury
• Coagulopathy.
• Complications:
  → CSF Leakage
  → Infection
  → Vascular lesions
• Cranioplasty.
Case# 11
Severe TBI, GSW, entrance, Lt PO, crossing to Rt sylvian,
Lucky survivor, with GOS 4/5 (mild left side spasticity. No visual field defect, very little cognitive impairment)
It was decided not to go after the bullet! F/U angio
MGH (1995 -2006)

AR. Ajlan

- 48 cases. (4 cases/ year )
- Male:female 44:4
MGH (1995 -2006)

• 17 out of 48 was suicidal attempt.
• All → died
• 2 out the 17 females.
  Mechanism:
• 65% from the side
• 27% through oral cavity.
Mortality

- Mortality 36 cases (75%)
- 11 died before arrival. → (30%)
- 13 died same day (ER/ICU) → (30%)
- 9 died in the first 14 days
- 2 survive for 3 months.
Survivors

• Only 6/12 survivors had intracranial involvement.
• All of them had immediate surgery.
• 50% had good outcome.
• The other 6 extracranial involvement had good recovery (5 GCS outcome scale)
Conclusion

- PBI is far less common than close TBI
- PBI in civilian population is caused by different varieties of projectiles
- Degree of damage depends on variety of factors: velocity and importance of neurovascular structures involved in the pass, etc
- Non missile, low velocity projectile is an uncommon cause of PBI, with better prognosis than missile injuries
- Missile, high velocity projectile (Gun shots) are more common than non-missile injuries and often are fatal
- Among survivors, infection & seizure is more common than close TBI
Thank you