Thoracic Trauma
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Basic Facts
• Trauma to the thorax is the second most common injury found in trauma patients
  — 764,000 admissions in 2004 alone
  — It’s estimated that 10% of trauma patients have at least one rib fracture
  — Even more (15%) may have pulmonary contusions
  — These injuries rarely occur in isolation — 94% of patients with rib fractures had other injuries

Basic Facts
• Thoracic trauma causes up to 25% of deaths in trauma victims
  — This is second only to traumatic brain injury in mortality
  — The risk of death after rib fractures increases with:
    • Age greater than 65
    • More than 3 rib fractures
    • Presence of comorbidities like heart disease or diabetes
    • Development of pneumonia while on the ventilator

Basic Facts
• The most frequent mechanism of injury is motor vehicle crash (MVC)
  — Up to 80%
• Falls are a distant second in many studies
  — About 20%
  • As a population ages, falls become more common and MVC becomes less common.
  • Assault with blunt object and sports injuries are infrequent causes of thoracic injury

Mechanisms of Injury
• In the broadest sense, injuries to the chest fall into two categories:
  — Direct impact (steering wheel into chest, fall from height)
  — Deceleration (steering wheel into chest, fall from height)
  • No, this isn’t a typo...

Basic Facts
• Thoracic trauma commonly results in bony injury
  — Rib fractures
  — Sternal fracture
  — Clavicle and scapular fracture
• The underlying organs and structures are also at risk for damage
  — Blunt cardiac injury and myocardial dysfunction
  — Pulmonary contusion
  — Pulmonary laceration
  — Tracheobronchial injury
  — Pneumothorax and hemothorax
More on Mechanisms

• Direct impact involves compressive forces across the bony structures of the chest.
  – These forces are usually directed antero-posteriorly (head-on collision) or laterally (T-bone accident)
  • Compression results in deformation of the somewhat elastic ribcage
  • Compression of a rib beyond 20% deformity results in a fracture
    – Compression beyond 40% is usually required for flail chest
  • Overpressure to the lungs can occur at impact (especially if the breath is held in Valsalva by reflex)
  • Compression forces are transmitted across the chest wall to the structures beneath

More on Mechanisms

• Deceleration refers to the problem of the organs of the chest slowing (at the time of impact) at varying speeds
  – The sternum stops first (on the steering wheel)
  – The heart stops milliseconds later (on the sternum)
  – The lungs stop against the deforming ribcage
  • Stretching occurs to both the heart and the lungs, since they are tethered centrally (to each other, to the posterior chest wall, and to the great vessels)
    • Stretching occurs at the organ level (tearing of the trachea or bronchus, or of the aorta)
    • It also occurs in the tissues at every tether point – each bifurcation from the bronchus to the alveoli
    • At impact, the ribs are moving toward the decelerating lungs; some areas of lung are dragged across the ribs harder than others because of the impact. This causes localized severe shearing

More on Mechanisms

• Deceleration / Shear injuries
  – Pulmonary laceration
    • Deceleration against adhesions or at bronchial bifurcations
    • Also against deforming ribs
  – Pulmonary contusion
    • Shear at the capillary level
    • Tracheobronchial disruption
      • Shear at the macro level
      • Rarely seen in the hospital because it’s so immediately lethal, both in loss of airway and because of the immense forces required
        – Think about the snapping towel

More on Mechanisms

• Rib fractures have varying implications based on their location
  – Ribs 1-3 (the top of the rib cage, behind the clavicles) are fixed in place
    • Fractures of these ribs, as with scapular fractures, are markers for high-impact force to the chest wall
  – Ribs 4-8
    • These ribs move with respiration
      • Flail chest usually involves these ribs
  – Ribs 8-11
    • Markers for intra-abdominal injury when fractured
      • Right sided rib fractures carry a 20-55% risk of concomitant liver injury
      • Left sided rib fractures have a 22-28% risk of associated splenic injury

More on Mechanisms

• Direct impact injuries:
  – Rib fractures – first the ribs bend, then they break
    • Younger patients withstand more force
  – Pulmonary contusion
    • Force transmitted through the chest wall
  – Pulmonary laceration or pneumothorax
    • Laceration by broken ribs
    • Overpressure from impact during Valsalva
  – Sternal fracture, clavicular fracture, scapular fracture
    • These fractures are associated with pulmonary contusions – not necessarily because the lung is being struck, but because of the force required to fracture these bones

More on Mechanisms

• Clinical considerations in the ED
  – Posterior rib fractures are difficult to appreciate on CXR – especially on patients strapped to a backboard
    • On the other hand, they’re often hard to see in upright PA/Lateral films...
  – If a patient receives isolated rib X-rays, a formal CXR showing both lung fields is a good idea as well.
  – Rib fractures should be suspected in patients with exquisite tenderness to palpation of the chest wall
    • Bony crepitus may also be noted
    • Additional clues: seatbelt sign, bruising, significant splinting
Rib Fractures

- Rib fractures cause pulmonary dysfunction directly and indirectly
  - Associated with pulmonary contusion
  - Pain-related hypovolemia
    - The elderly are particularly susceptible, which is why many major studies demonstrate mortality up to 35% or 40% in elderly patients with multiple rib fractures (≥3)
  - Progressive atelectasis and hypoxia
    - Patient may require aggressive pulmonary toilet with modalities that provide positive pressure
    - The end result of pain-related hypovolemia and atelectasis; also related to the decreased lung compliance in contused lung

Flail Chest

- Defined most commonly as three adjacent ribs each broken in two places
- About 10% of patients who have blunt chest trauma will have a flail segment
- Ribs become brittle with age. Young patients with flail chests have absorbed much more force than elderly flail patients
  - The likelihood of underlying severe pulmonary contusion is higher in younger patients
  - Rib fractures in children (without an extraordinary mechanism) should prompt evaluation for abuse
  - The corollary is that pulmonary contusion should be anticipated in children even in the absence of rib fractures

Flail Chest

- Clinical Considerations in the ED
  - Patients can have their flail segment diagnosed in many ways
    - Inspection: the chest wall contour is “weird” on one side, when looking up from the foot of the bed
    - Palpation: “mushy” or crackly chest wall
    - Auscultation: crepitus, either from broken ribs or from soft tissue air bubbles (sub-cu emphysema)
    - May be seen on CXR, if the flail is anterior and lateral
    - Most reliably diagnosed on CT

Pulmonary Contusion

- Appear on CT or CXR as infiltrates that cross lung fissures and lobes (so are not infiltrates related to aspiration)
- On CT, do not show the classic dependent pattern that aspiration does
- Blood leaves the vessels and enters the parenchyma and the alveoli of the injured lung (“bruised lung”)
- This can be due to direct impact or to shear injury

Pulmonary Contusion

- Clinical Considerations in the ED
  - The patient who is unusually hypoxic (70’s to mid 80’s, as a ballpark) should be closely evaluated for contusion
  - Beware the patient who is “crazy” and will not keep their pulse oximeter on...
    - Sometimes the patient is high or badly concussed
    - Sometimes the patient is deeply hypoxic
  - Severe contusions will be visible on CXR even in the ED – but not all are. A “clear” CXR is not reassuring if the patient is still hypoxic.
  - Patients with severe hypoxia may require intubation in the ED
    - Even with intubation, hypoxia may persist; use of a PEEP valve or adding PEEP to the ventilator often helps. (More on this later)
Pulmonary Contusion

- Blood in the alveoli and the lung tissues causes pulmonary dysfunction in several ways
  - Compliance in the injured lung decreases
    - Patients work harder to inhale the same VT
    - In ventilated patients, higher inspiratory pressures are needed to move the same volume
      - Patients are “hard to bag”
    - Shunting increases V/Q mismatch; blood travels through regions of lung that are injured and poorly ventilated
    - Plasma proteins inactivate lung surfactant, causing alveolar collapse and shear stress on neighboring alveoli
  - The picture is depressingly similar to ALI or ARDS

Pneumothorax

- 10% or so across all trauma patients, but more like 30-40% of blunt trauma patients have PTX
- Causes
  - Penetrating trauma (stabs, gunshot wounds)
  - Laceration by broken rib (direct impact)
  - Laceration at previous scars (shear)
  - Ruptured bleb (overpressure)
  - Simple overpressure (impact while performing Valsalva)

Pneumothorax

- Clinical considerations in the ED
  - Deep sulcus sign
    - When a CXR is taken on a patient lying on his back, the classic apical pneumothorax is not seen
    - Air rises to the highest point in the chest – always has, always will
      - When the patient is lying flat, the highest point inside the thorax is at the anterior border of the diaphragm
      - This leads to abnormal lucency at the lung bases, and prominent diaphragmatic sulci
Pneumothorax

• Clinical considerations in the ED
  — Suspect PTX in the patient with unexplained hypoxia or shortness of breath
  — “Distant lung sounds” on the affected side is the classic diagnostic clue...for people who work in much quieter places than the usual ED or ICU.
    • Much more useful: listening for subcutaneous air by rocking the stethoscope over the chest wall and listening for the "rice krispies" sign
    • This is a specific sign of PTX. Nothing else causes it.

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• Clinical considerations in the ED and ICU
  — Be aware of the possibility of converting a PTX to a tension PTX when a hypoxic patient is intubated
    • Positive pressure ventilation can force more air into the chest cavity
    • This is clinically evident as a patient who was intubated for hypoxia, initially responds well, but...
      — Then desaturates again
      — Becomes “hard to bag” (rising peak inspiratory pressures)
      — Becomes hemodynamically unstable

• Clinical considerations in the ED and ICU
  — Be aware of the possibility of converting a PTX to a tension PTX when a hypoxic patient is intubated
    • In patients on pressure-regulated vents, this is seen as falling tidal volumes at the same pressure
    • In patients on volume-regulated vents, this is seen as rising peak inspiratory pressures for the same volume
    • This does not mean that patients should not be intubated or that PEEP should be avoided – the hypoxic patient in respiratory distress has to be alive to develop a tension PTX!

Complications of Thoracic Trauma

• Empyema
• Pneumatocele
• Lung abscess
• Persistent air leaks
• Bronchopleural fistula
• Pneumonia

Empyema

• Incidence is around 5% after chest trauma (blunt and penetrating)
• May occur after pneumothorax or hemothorax
• Risk factors include:
  — Inadequately drained collection of fluid or blood
  — Number of chest tubes and their positions
  — Associated pulmonary contusion
  — Development of pneumonia
**Empyema**

- Usually presents as an unexplained fever or WBC, days to weeks after the injury
  - This may be associated with pleuritic pain, increased work of breathing, and potentially new vent-dependent respiratory failure
- Diagnosed with CT (CXR may not be useful, depending on the size of the empyema)
- Treatment (from least to most invasive):
  - Chest tube drainage
  - Instilling a clot-buster (like alteplase) via the chest tube
  - Video-assisted thoracoscopic surgery (VATS)
  - Thoracotomy with decortication (pulling the pus layer off the lung)
- The longer it takes to diagnose the empyema, the more invasive the treatment will have to be.

**Pneumatocele**

- A laceration inside the lung, rather than along the surface
  - These are usually due to shear along prior scars or to overpressure
  - The elastic recoil of the lung means that a straight-line tear will end up spherical
- These will often resolve spontaneously, especially when the patient is not on a ventilator
- Pneumatoceles can develop into pulmonary abscesses, due to pooling of secretions and blood inside the cavity
- Not usually seen on CXR (unless there is an air-fluid level in the cavity) – seen frequently on CT (may be multiple, if the cause is overpressure)

**Persistent Air Leaks**

- When the pneumothorax won’t resolve completely (with a chest tube in) or there is a persistent leak noted in the pleur-evac
- May be related to positive pressure ventilation (a tear that would close spontaneously in a normally breathing patient is repeatedly blown open)
  - These resolve once the patient is off the vent
- Must consider proximal bronchial or tracheal injury
  - These injuries are exceedingly rare
  - Clues to the diagnosis include:
    - Large, continuous air leaks in ventilated patients
    - The ventilator is continuously setting off alarms due either to low airway pressures or lost tidal volumes
    - Air seen on CXR or CT around the trachea, the proximal bronchus, or massive subcutaneous emphysema
  - These may also be due to bronchopleural fistulae (more distal bronchial injury leaking into the thorax)
    - More common, possibly because the force required to disrupt the proximal airway is frequently lethal

**So What’s a Clinician to Do?**

- Keep the patient breathing
  - Also known as pain control
- Keep the airways open
  - Airway clearance techniques
  - Open up the lung
- Noninvasive and invasive ventilatory techniques
- And anything else left in the kitchen sink
  - Mucomyst, bronchoscopy, and outlandish ventilators, oh my!
- ...and what I do at work (a cautionary tale)
Pain Control

• Local and regional pain control: rib blocks
  – Local anesthesia is injected between the ribs, one rib above and below the fracture(s)
  • Pro: a temporary method of controlling pain
  • Con: a temporary method of controlling pain
    – Risk of pneumothorax is real
    – Can’t use on higher rib fractures safely
  – A newer take on this is the paravertebral catheter attached to a long-acting infusion system
    • Must be placed under sterile conditions
    • Risk of infection, pneumothorax

• Epidural anesthesia – a mainstay at many facilities for treatment of thoracic trauma
  – Usually include both opioids (fentanyl) and local anesthetic (bupivacaine)
  – Pro: can improve the work of breathing by decreasing splinting
    • The relief that the epidural provides can be dramatic
  – Con: many contraindications
    • Patients on anticoagulation – even prophylactically
    • Thoracic vertebral fractures
    • Patients who are not ready to come off the vent
    – Con: recent meta-analyses have not proven benefit in mortality, vent days, or hospital length of stay
    – Con: may actually increase morbidity and mortality in elderly patients (who must “move or die”)

Pain Control

• Whole-body pain control
  – Opioid infusions (e.g. fentanyl in intubated patients)
  – Patient-controlled anesthesia (PCA)
  – Dilaudid, morphine, fentanyl
  – Long-acting oral opioids
    • Oxy-contin, methadone (may be better in the elderly)
  – Adjunctive NSAIDs
    • Toradol...a wonder drug that is unfortunately not for everyone
      – Blending risk in trauma patients
    – Risk of kidney failure (particularly in the elderly, diabetic, hypertensive population...which is most of the state)

Airway Clearance Techniques

• Why is a trauma surgeon talking about airway clearance?
  – The last time I had a cystic fibrosis patient was...pretty much never
  – Emphysematous and bronchitic patients are common
  – Trauma itself usually includes an aspiration event
    • Abdominal overpressure” (or “impact”)
    • Loss of consciousness
    • Facial fractures bleed profusely
    • Many patients are intubated at the time of trauma
  – Blood in the airways should be cleared

  • Percussive therapy – CPT or vest percussion
    – Not popular in the rib fracture population
    – Not advised in unstable vertebral fractures or early closed head injury
    – Can be useful in patients who are unable or unwilling to cough independently

  • Fluder valve
    – Provides repeatable cough stimulation for the nonintubated patient

Venolatory Techniques

• Non-invasive techniques – the goal is to avoid intubation
  – Positive pressure ventilation (CPAP or bi-level PAP)
  – Recruit alveoli, which indirectly can decrease the work of breathing
  – Direct reduction in work of breathing
    • “Internal” or “Pneumatic” splinting of flail chest
      – This is likely the recruitment of contused lung under the flail segment
  – High flow nasal cannula
    • Effectively provides the equivalent of PEEP
    • Cannula is better tolerated than CPAP masks, particularly in patients with facial fractures
Venilatory Techniques

• Thoracic trauma results in both primary and secondary damage to lung tissue
  – Primary damage:
    • contusion (blood in the airways and parenchyma)
    • laceration
    • pneumothorax
  – Secondary damage: this should sound oddly familiar...
    • loss of surfactant and induction of inflammation
    • alveolar collapse
    • increased right-to-left shunt
    • decreased compliance
    • increased work of breathing
    • progressive hypoxemia and ventilatory failure

Venilatory Techniques

• Considering the secondary damage that flail chest, pulmonary laceration and contusion all can cause – it isn’t surprising that the majority of thoracic trauma patients will respond to the same therapies
  – And considering the litany of secondary pulmonary injury listed...it isn’t surprising that techniques for ALI and ARDS frequently have application in trauma.
    • Low tidal volumes based on patients’ ideal weights
    • Stepwise increase in PEEP in hypoxic patients (and minimum of 5 cm H2O in all patients)

Venilatory Techniques

• Rationale for PEEP
  – End-expiratory pressure helps to recruit alveoli
    • For venticulated patients, this is reflected as increased compliance and lower inspiratory pressures over time (at the same tidal volume in volume-control modes)
    – The same tidal volume is going into more lung volume
    – Recruited alveoli are spared repetitive open/close cycles that cause shear and inflammation at the cellular level
    – Theoretically, this may prevent extension of secondary injury – with the hope of avoiding ARDS entirely
    – As perfused (but collapsed) alveoli are opened for gas exchange, right-to-left shunt decreases

Venilatory Techniques

• Situations where more PEEP is not helpful
  – Persistent air leaks after pneumothorax
    • These may persist until the patient is extubated and performing normal negative-pressure ventilation
  – Conversion of simple PTX to tension PTX
    • This is noted as a caution, not as a rule; the treatment team must be vigilant for signs of PTX, and place chest tubes to prevent conversion to tension PTX.
  – Major tracheobronchial injury
    • May require pressure-control ventilation with extremely low tidal volumes (and permissive hypercapnia)
    • May require alternative ventilation modes
  – Air-trapping in COPD patients
    • Some COPD patients simply will not tolerate low tidal volume / higher frequency ventilation because they require very long expiratory times.

The Venilatory Strategies of Desperation

• ...when PEEP is not enough
  – Airway pressure release ventilation
    • This is considered a variant of extreme reverse I:E ventilation (the inspiratory phase can last up to 5 or 6 seconds, with the expiratory phase lasting less than one second)
    – Can permit independent breathing effort in patients, which means less sedation needed
    • Should be used very cautiously in patients who are not breathing spontaneously
  – High frequency oscillatory ventilation
    • Reduces the shear associated with repetitive open/close cycles at the alveolus
    • Can be useful in patients with persistent or massive air leaks (or bronchopleural fistula)
    • Has been used in patients requiring independent lung ventilation (with a conventional ventilator for the uninjured lung)

The Venilatory Strategies of Desperation

• ...When PEEP is not enough.
  – Severe bilateral pulmonary contusion
  – ALI from fat embolus
  – Severe single pulmonary contusion
  – Massive air leak from chest wall destruction
  – Single lung ventilation
    • Can be used in massive air leak or in single-sided pulmonary contusion
    • Put the good lung down...to pull blood to the ventilated lung by gravity
  – Independent lung ventilation
    • Used, for example, if one lung has a massive air leak, and the other a severe contusion
      • Can use a double lumen tube
      • Some physicians have placed two ET tubes via tracheostomy
      • Remember that 55% of the usual Vt should go to the right lung
What Do We See at Methodist?

- 43% of our patients have “fall” as their mechanism of injury
  - Fall from height, fall from ladder, fall from bed.
  - This reflects the older and rural populations in central Iowa.
  - In our patients over 65 with multiple rib fractures, nearly two-thirds have fallen down.
- 30% are involved in MVC
  - Motorcycles are included...ATVs are not.
- 8% suffer penetrating injury
  - Stabs, gunshot wounds, the occasional road sign...

This Week at Methodist

- Two pediatric pulmonary contusions
  - Neither child has rib fractures.
  - One child is intubated, the other is not.
- Two adult pulmonary contusions
  - One with rib fractures, one without.
- Three adults with multiple rib fractures
  - Two of these patients are older than 75.
  - None of them have yet to require intubation.
  - Two flail chests
    - One flail chest patient also fractured the sternum.

What Happens...

- In the ED?
  - A supine CXR is taken on more than 90% of patients within the first 10 minutes of evaluation.
  - The chest wall is exposed, examined, and auscultated.
  - Patients with PTX large enough to be obvious on a supine CXR have chest tubes placed within the first 30 minutes of evaluation (baring more serious injuries).
  - The patient that almost got away...

What Happens

- To intubated patients in the ED?
  - Patients who arrive intubated have their airways re-checked for tube movement during transfer.
  - Starting tidal volumes range between 400 and 600 in adults.
  - Starting rates range between 16 to 20.
  - I start asking for a PEEP valve to be placed in-line with the bag-valve mask...starting between 5 and 7, occasionally 10.
  - Patients who require intubation receive ETT from surgical residents, anesthesiologists, or helicopter personnel.
  - I start asking for a PEEP valve to be placed in-line with the bag-valve mask.

What Happens

- To patients with multiple rib fractures, pulmonary contusion, or flail chest in the ED?
  - Patients in acute hypoxic or respiratory distress are intubated.
  - The remainder...enter rib fracture boot camp in the ICU.
  - Aggressive mobilization, when possible, with PT.
  - Continuous iv and/or oral pain control.
  - Frequent airway clearance and recruitment therapies.
    - High-frequency positive pressure nebs up to 6 times daily.
    - Occasionally, use of CPAP as an intermittent recruitment tool.
  - If scheduled recruitment therapies do not maintain ventilation and oxygenation, the patient is placed on continuous positive end-expiratory pressure (CPAP, bi-level PAP, high-flow nasal cannula).

The Obligatory Clean-Up Slide

- Questions, comments are welcome...so long as they are wildly appreciative.
- Speaking of wild appreciation – the Trauma team could not do what we do without the assistance and guidance of the Respiratory Therapy team.
  - Particular thanks to Julie Jackson, who invited me to speak here today.
  - And thank you for your time and attention!
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