Introduction

Neurologic injury remains one of the leading causes of death and long term functional deficits despite recent advances in management. The diagnosis and treatment of neurologic injuries require parallel efforts to assess the patient clinically and radiologically. The timing and selection of radiologic investigations remain a source of controversy. Advancing imaging modalities yield diagnoses previously overlooked. Medicolegal concerns influence clinical decisions. Decision rules and protocols designed to reduce unnecessary costs, radiation exposure, and clinical delays can seem complex, contradictory, and excessively rigid. Resources are progressively scarce. It is important to have a knowledge of how selective use of advanced imaging modalities will improve patient care.

How are neurologic catastrophic conditions defined?

Catastrophic conditions are those which have a significant risk of mortality, if the diagnosis is emergently missed.

Critical traumatic conditions are those which have a significant risk of morbidity, if the diagnosis is delayed (e.g., cervical spine injuries, subacute hemorrhage, or transient cerebral ischemia).

Neurologic Injury: Parallel Processing of Information

1. Consider the high risk differential diagnosis, on the basis of clinical history, physical examination, and laboratory studies.
2. Concurrently stabilize, initiate imaging sequence, and/or contact appropriate surgical consultants.
3. Confirm benign etiologies directly, or indirectly after formal exclusion of the catastrophic differential diagnosis.

3 Catastrophic conditions

- Intracranial hemorrhage
  - Traumatic
    - Subdural hematoma
    - Epidural hematoma
    - Intracerebral hemorrhage
  - Vascular etiologies
    - Aneurysm rupture
    - Hemorrhagic arterio-venous malformation
    - Hemorrhagic Venous angioma
- Acute intra-axial ischemia and infarction
- Intracranial and axial infection
  - Meningitis
  - Diskitis
  - Abscess
2 Critical Injuries: Axial and Intra-axial Trauma

- Axial fractures
  - C-spine
  - T-spine
  - Lumbosacral
- Intra-axial
  - Contusions
  - Concussions
  - Petechial hemorrhage

General Vital Sign Indications for Catastrophic Differential Diagnosis

1. Tachycardia or bradycardia (heart rate <50)
2. Tachypnea or bradypnea (respiratory rate <7)
3. Significant pyrexia or hypothermia
4. Hypotension and hypertension
5. Acute hypoxia
6. Pain severity
7. Weight loss

Local Vital Sign Indications for Neurologic Differential Diagnosis

1. Glasgow Coma Score
   - Adult
   - Pediatric
2. Cranial nerve functional deficits
   1. Visual acuity
   2. Hearing loss
   3. Anosmia
3. Motor strength
4. Reflex changes
5. Peripheral sensory deficits

Clinical Catastrophic Criteria

- Acuity, severity, progression, persistence, refractory, atypical or unexplained:
- Critical acute symptoms (e.g., severe headache, neck pain, back pain, palpitations, or respiratory irregularity; nausea, vomiting, distension; paresthesia, weakness, or paralysis)
- Selective physical findings (neurologic deficits; blood pressure fluctuation, rhythm disorders, bradypnea or tachypnea; altered bowel or urinary function (incontinence or retention); loss of reflexes, motor function, or sensation; hemotympanum, periorbital ecchymosis).
- Aberrant laboratory, electrocardiographic, or plain radiographic abnormalities (e.g., axial imaging).

Imaging Modalities

- Conventional Radiographs and Special Views
- CT: Incremental, Spiral, Angiographic
  - US: Gray Scale, Color Doppler, Amplitude Angiography
- MR: MRI and MRA
- Arterial Catheterization

Craniofacial Injury: Strategy

- Catastrophic Craniofacial Findings
- Vital Signs
  - History
- Neurologic Examination
- Advanced Imaging Options
  - 1. CT/CTA
  - 2. MRI
  - 3. Angiography
Principles of facial imaging

- If you can name the particular bone, plain film imaging is appropriate:
  - Nasal spine
  - Mandible series (preferred: orthopantomogram)

- If two or more bones are involved, CT is indicated. Do not order (but your institution may require):
  - Facial films
  - Sinus series
  - Orbital series
  - TMJ series
  - Skull series

Case 1

30 year old homeless male, intoxicated, is involved in fistfight, with multiple facial abrasions, and paranasal sinus tenderness.
**Principles of Cranial Imaging**

- Universal decision rule:
  - Acuity, severity, progression, persistence, refractory, atypical and unexplained
  - Symptoms:
    - Headache, nausea and vomiting, confusion, vertigo, memory deficit, weakness, paresthesia, dizziness, bleeding from ears, new CN deficits.
  - Physical findings:
    - GCS decline
    - Neurologic deficits
    - Supraclavicular injuries
  - Laboratory, electrocardiographic, or plain film findings, such as:
    - Respiratory acidosis
    - ST segment depression or elevation
    - Associated injuries: C-spine fractures

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**CT versus MRI: Controversy**

<table>
<thead>
<tr>
<th>CT vs. MRI</th>
<th>MRI</th>
<th>CT</th>
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<tbody>
<tr>
<td>Sensitivity (ICH)</td>
<td>100%</td>
<td>97%</td>
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<tr>
<td>Radiation dose</td>
<td>0</td>
<td>1/1000 cancer rate</td>
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<tr>
<td>IQ impact</td>
<td>No known change</td>
<td>Diminished rate</td>
</tr>
<tr>
<td>HS graduation rate</td>
<td>No known change</td>
<td>Diminished rate</td>
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**CT versus MRI: Controversy**

<table>
<thead>
<tr>
<th>Sedation</th>
<th>CT</th>
<th>MRI</th>
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<tbody>
<tr>
<td>Often in children</td>
<td>Often in children</td>
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<table>
<thead>
<tr>
<th>Cost per machine</th>
<th>CT</th>
<th>MRI</th>
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<td>0.25 million</td>
<td>1.0 million</td>
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<table>
<thead>
<tr>
<th>Cost per study</th>
<th>CT</th>
<th>MRI</th>
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<td>High</td>
<td>Intermediate</td>
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<th>After hours access</th>
<th>CT</th>
<th>MRI</th>
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<tr>
<td>Difficult</td>
<td>Easy</td>
<td></td>
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**SAH: Emerging controversy**

**Imaging sequence**

1. Non-contrast CT
2. Lumbar puncture
3. CTA if MRI + ICH.

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**Types of Intracranial Hemorrhage**

- **Epidural hematoma**
  - Common mechanism: meningeal artery laceration, often associated with temporal-parietal fractures

- **Intraparenchymal hematoma**
  - Common mechanism: contusion with potential for progression

- **Subdural hematoma**
  - Common mechanism: injury to bridging dural veins

- **Subarachnoid hemorrhage**
  - Common mechanism: traumatic aneurysm rupture

- **Intraventricular hemorrhage**
  - Common mechanism: extension of intraparenchymal hematoma
Case 2

75 yo Chinese-American male, with no prior medical history, awoke at 2300 hours with n/v and left sided weakness, progressing to witnessed seizures.

Case 2: CT and MRI

Case 3

61 year old Hispanic female with severe headache and nausea, become apneic in transport, with run of ventricular tachycardia.
Contusions and Intracerebral Hematomas

Contusions can, in a period of hours or days, evolve or coalesce to form an intracerebral hematoma requiring immediate surgical evacuation.

This occurs in approximately 20% of patients and is best detected by repeating the head CT scan within 12 to 24 hours after the initial scan. ATLS

C-spine interpretation: Architectural principles

- **Lateral projections**
  - Counting (Marshall’s law)
  - Are all the vertebral bodies visible, including T1?
  - Continuity
    - Are the anatomic curves continuous?
  - Conformance
    - Are the transitions between vertebral bodies regular, with respect to size and intervertebral spaces?

- **Anterior projections**
  - Symmetry
    - Dens and C1
    - C1 and C2
  - Sinusoidal configuration
    - Lateral masses
  - Scoliosis
    - Muscles, ligaments
  - Occult fracture

C-spine: the lateral view of the lateral masses

- Contour transitions

C-spine interpretation guidelines

- Prevertebral STS
- Anterior longitudinal line
- Posterior longitudinal line
- Spinal laminar line
- Posterior process line
- Dens-basion distance
C-spine: the AP view of the dens
- Symmetry

C-spine: the AP view of the dens
- Symmetry

C-spine: the AP view of the lateral masses
- Sinusoidal contour

Indications for C-spine Films:
- Severe pain
- Midline tenderness
- Unrestrained occupant
- Ejection
- Neurologic deficit
- Intoxication
- Altered level of consciousness
- Mechanism
- Velocity
- Intrusion
- Rollover
- Other injuries
- Brain
- Distracting pain

* = NEXUS exclusion criteria (NEJM Jul, 2000): implicit indications for imaging.

NEXUS
- 34,069 patients

NEXUS
- Five criteria to be classified as low probability of injury:
  - no midline cervical tenderness
  - no focal neurologic deficit
  - normal alertness
  - no intoxication
  - no painful, distracting injury
- Individual criteria not compared
- NPV 99.8%
Nexus Study

34,000 Patients, 23 Centers
5 Criteria: No posterior midline tenderness, intoxication, altered consciousness, neurological deficits, distracting injuries. 99.6% Sensitivity, but 12% Specificity.

Canadian C-Spine Rule (I)
- 8924 Adults
- 100% Sensitivity and 42.5% Specificity
- 1) Is there any high-risk factor that mandates radiography (i.e. age > 65, dangerous mechanism of injury, or paresthesias)?
- 2) Is there any low-risk factor present that allows safe assessment of range of motion (i.e. simple rear-end motor vehicle collision, sitting position in ED, ambulatory at any time since injury, delayed onset of neck pain, or absence of midline tenderness)?

Canadian C-Spine Rule (II)
- 3) Is the patient able to actively rotate neck 45 degrees to left and right regardless of pain?

C-spine: dens injury
- Asymmetry

CT C-spine: the lateral view of the dens
- Technique:
  - Finest possible cuts of level of abnormality
  - Beware of motion artifacts
  - Cortical discontinuity
  - Double density sign

CT C-spine: the axial view of the dens
- Asymmetry
CT of C1-C2 More Sensitive Than Plain Films

- Study of 202 patients with traumatic brain injury. Link, et al, found 5.4% of patients had C1 or C2 fractures and 4% had occipital condyle fractures not visualized on three-view radiographs.
- Blacksin and Lee evaluated 100 consecutive trauma patients, found 8% frequency of fractures of the occipital condyle (3%) and C1-C2 (5%) not detected on cross-table lateral c-spine.
- http://www.east.org

Flexion-extension Films: ATLS guidelines

- Persistent neck pain, without radiographic changes
- Non-acute CT scan, with suspected degenerative or chronic spondylolisthesis
- The degree of angulation must be determined by the patient, and limited by level of tolerance.

PEDIATRIC C-SPINE

- Increased cranial size, with increased ligamentous laxity
- Pseudosubluxation of C2 on C3 and C3 on C4 OK below age 8. Use posterior cervical line to rule out pathology

Thoracic Imaging: Radiologic Sequence

- Imaging evaluation of acute chest trauma divides into five typical paths:
  1. Chest Radiograph: general survey
  2. Thoracic spine series
  3. US (e.g., myocardial contusion and pericardial effusions)
  4. CT/CTA (e.g., pulmonary contusion, aortic transection, pericardial injury)
  5. MRI: assessment of cord injury
T and LS-spine interpretation:
Architectural principles
- Lateral projections
  - Counting (Marshall's law)
  - Symmetry
  - Continuity
- Anterior projections
  - Symmetry
  - Continuity
- Posterior projections
  - Symmetry
- Scoliosis
- Muscle spasm
- Ligamentous injury
- Occult fracture

Parallel Algorithm for Abdominal Trauma

Case 4
- 71 year old with hx of chronic back pain, depression, and seizures, increasing over the past several months, and worse today.
- PDx: extreme weakness.
Severe Pelvic Fractures

- Early transfer to a Trauma Center
- Strongly recommended (ATLS)

Universal Decision Rule in Axial and Extremity Injuries

- If focal skeletal tenderness is demonstrated, conventional radiographs.
- CT (or MRI) for atypical, asymmetric, askew, or avulsed findings.
- Advise patients that “occult fractures and internal derangements cannot be excluded, and interval evaluation may be required.”
- Splint.
- Hard collar for cervical spine strain.
- Appropriate splint for extremity injuries.
- Formal radiologic interpretation in less than 24 hours.
- Formal follow-up:
  - Diminished or asymmetric range of motion in children, concurrent orthopedic discussion or consultation.
  - Neurologic deficits, central or peripheral emergent consultation.
  - Instability: concurrent orthopedic discussion or consultation.
  - Interval evaluation in adults: e.g., <7 days with appropriate specialist (e.g., orthopedist, maxillofacial, neurosurgical, or otorhinolaryngologist).

Appendicular Skeletal Trauma

- Catastrophic Appendicular Findings
  - Clinical Information
  - Standard Diagnostic Testing
  - Advanced Imaging Options
    1. Laboratory
    2. CT/CTA
    3. MRI
    4. Angiography

2 Catastrophic neurologic injuries

- Child abuse, with potential fatal outcome
- Neurologic compromise from fracture-dislocations

Critical Injuries: Axial and Extremity Trauma

- Fractures
- Dislocations
- Subluxation

Local Vital Sign Indications for Traumatic Differential Diagnosis

1. Injury site related pain or tenderness
2. Aberrant range of motion
3. Aberrant muscle strength (scale of 5)
4. Aberrant sensation
5. Aberrant pulses
  1. Diminished pulse to palpation
  2. Peripheral capillary refill
  3. Peripheral pulse oximetry
Clinical Catastrophic Criteria

- Acuteness, severity, progression, persistence, refractory, atypical, or unexplained:
  - Critical acute symptoms (i.e., pain at rest, pain with motion, immobility, subjective paresthesia)
  - Selective physical findings (diminished range of motion, severe tenderness to palpation, loss of motor function, loss of sensation, loss of pulses, pallor, presence of extensive hematoma)
  - Aberrant laboratory (declining Hematocrit, aberrant peripheral or central pulse oximetry; plain radiographic abnormalities)

Imaging Modalities

- Conventional Radiographs and Special Views
- CT: Incremental, Spiral, Angiographic
- US: Gray Scale, Color Doppler, Amplitude Angiography
- MR: MRI and MRA
- Arterial Catheterization

Universal Decision Rule in Axial and Extremity Injuries

- If focal skeletal tenderness is demonstrated, conventional radiographs.
- Comparison view in children (or use of Keats).
- CT (or MRI) for physical, asymmetric, acute, or atypical findings.
- Advise patients that “occult fractures and internal derangements cannot be excluded, and interval evaluation may be required.”

Appendicular Skeletal Trauma

Vital Signs
History
Examination

References

3. Scott A. Hoffinger, Pediatric Emergency Radiology, Topics in Emergency Medicine, (ME. Kernberg, MD, Editor), 2004
4. Radiation Risks and Pediatric Computed Tomography (CT): A Guide for Health Care Providers, National Cancer Institute (USA) and Society for Pediatric Radiology, 2002 (modified for Table 1).
After a closed head injury, with transient loss of consciousness, a 2 year old female infant has persistent nausea and vomiting. Imaging should include:

1. None  
2. Skull films  
3. Head CT scan  
4. Head MRI