Controversies in CT Imaging for Trauma

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Disclosure

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Outline

- Early trauma CT
- The “Pan-Scan”: Whole body CT in Trauma
- Blunt splenic trauma and angioembolization
- Impact of CT’s increasing sensitivity:
  - Detection of early & minor disease.
  - The “incidentaloma”
- Radiation dose considerations

ED CT Utilization Still Rising

- > 80 million total CT scans / year in USA in 2010 (25% ED)

Image adapted from Levin D, Rao VM, Parker L, JACR 2013 9(11): 795
**Early Trauma CT**

CT For Polytrauma

- High accuracy for a wide range of injuries\(^1\).
- Low missed injury rate\(^2\,^3\).
- Can be performed rapidly\(^2\,^3\).


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**Time to Complete a Trauma CT**

Harborview Medical Center, July-August 2005\(^1\).

Trauma patients ISS > 15.
Time to get a CT.
Some other locations have had similar results\(^2\).

Time in ED is a Risk Factor for Mortality

- The longer the hemodynamically unstable patient stays in the ED, the higher the risk of death.\(^1\)\(^2\).
  - Mortality rose to 8.3% if patient in ED for 4-5 hours.\(^1\)
  - Outcome better if primary diagnosis < 40 mins of arrival vs. > 50 mins.

- Causes of long stays:
  - MRI for spine fractures.
  - Multiple consulting services: “Consultarrhea.”

Why would earlier CT enable us to do?

- Earlier identification of:
  - Surgical head injury.
  - Primary bleeding site.
    - i.e. pelvis vs. intra-peritoneal, vs. chest.
  - Non-surgical causes of hypotension.
- Best way of controlling circulation is to stop the bleeding.
  - Pelvic fractures requiring angioembolization.
  - Time to angioembolization affects survival.\(^1\)

Speed Improvements from Early WBCT

<table>
<thead>
<tr>
<th>Author</th>
<th>Patients</th>
<th>Standard Protocol (mins)</th>
<th>Early WBCT (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weninger et al(^1)</td>
<td>185 old 185 ED-CT</td>
<td>104 +/- 21</td>
<td>70 +/- 17</td>
</tr>
<tr>
<td>Wurmb et al(^2)</td>
<td>79 std 82 resus CT</td>
<td>70</td>
<td>23</td>
</tr>
<tr>
<td>Fanucci et al(^3)</td>
<td>20 segmented 26 single-pass</td>
<td>32</td>
<td>22 mins</td>
</tr>
<tr>
<td>Sedlic et al(^4)</td>
<td>34 Segmented 33 single pass</td>
<td>18</td>
<td>10</td>
</tr>
</tbody>
</table>


Rapid Whole Body CT: Outcome

- Prospective study in 14 French hospitals
- WBCT (N = 1,696) vs selective (N = 254).
  - Crude mortality rate @ 30 days
    - WBCT (16%) vs. selective CT (22%)
  - OR for death to 0.58 with injury adjustment.

Yeguiayan J et al Critical Care 2012, 16:R101
REACT-2

- Multicenter international trial.
  - 6 high-volume trauma centers (Nederlands).
- Control group:
  - Imaging based on ATLS guidelines.
- Intervention group:
  - Immediate whole body CT during primary survey (omitting radiography and FAST).
- Outcomes:
  - Mortality at 24 hours, 30 days, and 1 year.
  - Morbidity: Complications, interventions, readmissions, length of ICU stay and ventilation.
  - Radiation exposure
  - Quality of life.


Splenic Organ Injury Scale - 1994

- Fundamental objective of the OIS:
  - To provide a clearer [anatomic] description to facilitate comparison of an equivalent injury managed in one fashion versus another
  - Not to assign prognostic value to a specific injury
  - Ordinal
- Based on surgical / pathologic appearance of injuries.
- However:
  - In 2014, nearly all splenic injuries for which a conservative management is contemplated are diagnosed with CT.
  - OIS now used to guide clinical decision making.
  - Data based on outcomes research.
  - CT appearance & OIS description not interchangeable.
  - No description of vascular complications on CT.

Whole Body CT in Trauma – The PanScan
### AAST Splenic Grading - 1994

<table>
<thead>
<tr>
<th>Grade</th>
<th>Injury type</th>
<th>Description of injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Hematoma</td>
<td>Subcapsular, &lt;10% surface area</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Capsular tear, &lt;1 cm parenchymal depth</td>
</tr>
<tr>
<td>II</td>
<td>Hematoma</td>
<td>Subcapsular, 10%-50% surface area; intraparenchymal, &lt;5 cm in diameter</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>Capsular tear, 1-3 cm parenchymal depth that does not involve a trabecular vessel</td>
</tr>
<tr>
<td>III</td>
<td>Hematoma</td>
<td>Subcapsular, &gt;50% surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma &gt; 5 cm or expanding</td>
</tr>
<tr>
<td></td>
<td>Laceration</td>
<td>&gt;3 cm parenchymal depth or involving trabecular vessels</td>
</tr>
<tr>
<td>IV</td>
<td>Laceration</td>
<td>Laceration involving segmental or hilar vessels producing major devascularization (&gt;25% of spleen)</td>
</tr>
<tr>
<td>V</td>
<td>Laceration</td>
<td>Completely shattered spleen</td>
</tr>
<tr>
<td></td>
<td>Vascular</td>
<td>Hilar vascular injury with devascularizes spleen</td>
</tr>
</tbody>
</table>

Advance one grade for multiple injuries up to grade III.


http://www.aast.org/library/traumatoools/injurscoringscales.aspx#spleen

### CT-based Splenic Grading System

<table>
<thead>
<tr>
<th>Grade</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Subcapsular hematoma &lt; 1 cm thick</td>
</tr>
<tr>
<td></td>
<td>Laceration &lt; 1 cm parenchymal depth</td>
</tr>
<tr>
<td>2</td>
<td>Parenchymal hematoma &lt; 1 cm diameter</td>
</tr>
<tr>
<td></td>
<td>Laceration 1–3 cm in parenchymal depth</td>
</tr>
<tr>
<td>3</td>
<td>Splenic capsular disruption</td>
</tr>
<tr>
<td></td>
<td>Subcapsular hematoma &gt; 3 cm thick</td>
</tr>
<tr>
<td></td>
<td>Laceration &gt; 3 cm in parenchymal depth</td>
</tr>
<tr>
<td>4a</td>
<td>Active intraparenchymal and subcapsular splenic bleeding</td>
</tr>
<tr>
<td></td>
<td>Splenic vascular injury (pseudoaneurysm or arteriovenous fistula)</td>
</tr>
<tr>
<td></td>
<td>Shattered spleen</td>
</tr>
<tr>
<td>4b</td>
<td>Active intraperitoneal bleeding</td>
</tr>
</tbody>
</table>


### CT Based Splenic Grading

- Active vascular extravasation (aka “contrast blush”), and other splenic injuries better predictors of failure of non-operative management (NOM) than many AAST findings.
  - Some problem with study design (self-fulfilling).
- For hemodynamically stable adults w splenic injury (small # [23 overall] of failed NOM):

<table>
<thead>
<tr>
<th>Grade</th>
<th>Failed NOM (No AE) %</th>
<th>Failed NOM (With AE) %</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>II</td>
<td>2</td>
<td>0</td>
<td>0.318</td>
</tr>
<tr>
<td>III</td>
<td>5</td>
<td>0</td>
<td>0.562</td>
</tr>
<tr>
<td>IV</td>
<td>23</td>
<td>3</td>
<td>0.04</td>
</tr>
<tr>
<td>V</td>
<td>63</td>
<td>9</td>
<td>0.03</td>
</tr>
</tbody>
</table>


### Patient Selection for AE

- Hemodynamically “unstable” → OR.
  - High mortality rate for NOM in this group.
- Elevated risk of failure of NOM:
  - Active vascular extravasation “contrast blush”.
  - AAST grade IV and V injuries.
  - Decreasing Hb / HCT levels during NOM.

Bhullar IS et al, J Trauma 2012 72: 5, 1127
Questions that remain

- What to do about splenic pseudoaneurysms and AV fistulas?
- Smaller volumes of active contrast extravasation.
- Best angioembolization technique.
  - Proximal (main) splenic artery embolization
    - Open coils – lowers perfusion pressure, but maintains blood supply.
  - Distal (selective) splenic artery embolization.
    - Infarction of spleen – necrosis (pain) and potential infection.
- Hybrid approaches.

Splenic Laceration with Pseudoaneurysm:
- Arterial Phase CT
- Venous Phase CT
- Lesion becomes invisible on standard venous phase

Splenic Laceration with Pseudoaneurysm:
- Arterial Phase CT (Coronal)
- Cath Angio (Celiac Inj)
**Splenic Artery Embolization**

**Arterial Phase CT**

**Portal Venous Phase CT**

*Note: Lesion is invisible on standard venous phase*

**Follow-up CT Two weeks later**

**Angioembolization**

*Cath Angio (Splenic art. Inj)*

*Cath Angio (Splenic art. segmental Inj)*

*Pseudoaneurysm*
Intra-splenic.
Appears as rounded dense puddles on CT.
Density mirrors vascular phase on CT.

- Density on arterial phase = density of aorta / splenic artery.
- Density on portal venous phase = density of portal / splenic veins.
- Density on delayed phase = density of IVC.

Tend to be invisible on portal venous phase and delayed phase CT.
Dense area does NOT increase in size with longer duration.
Density of lesion drops with progressively duration after contrast injection.

Splenic Laceration with Active Bleeding (Vascular Contrast Extravasation)

Contrast Extravasation (Active Bleeding): Appearance on CT.
Active Contrast Extravasation: Appearance on Dynamic Contrast CT

- Increases in quantity/size with increasing time following contrast injection.
- Volume visible on CT:
  - Arterial phase < portal venous phase < delayed phase.
- Increases in density during phases:
  - Arterial phase < portal venous phase < delayed phase.
- May appear to arise or “squirt” from laceration.
- Spreads in peritoneal space / Irregularly shaped.

Impact of CT’s increasing sensitivity:

Trauma Surgeon:
“CT’s are too sensitive: you guys report too many things!”

Radiologist:
“Don’t blame the scanner, it’s just that you (and we) don’t have a clue what to do with all these findings.”

CT’s High Sensitivity for Disease (and Pseudo-disease)

- Detection of early disease.
  - e.g.
    - “Occult” pneumothorax
    - Free intraperitoneal fluid
    - Pulmonary embolism
    - Active vascular extravasation
- Detection of diseases unrelated to trauma.
  - The “incidentaloma.”

Occult Pneumothorax
Occult pneumothorax.
- 2–15% of chest trauma patients.
- Pneumothorax detectable with CT (or US) that is not seen on a chest radiograph.
- Prior to near-routine CT scanning of the C spine and torso, many would have gone undetected.

Management: conservative vs. thoracostomy tube.
- Overall failure rate with conservative Mx: 6%
  - Higher failure rates:
    - Large pneumothoraces
    - Positive pressure ventilation.
- Nowadays tendency towards observation.
Laparotomy and Free Fluid

Table 5 Difference of Opinion Regarding the Significance of Free Intra-abdominal Fluid without Solid Organ Injury on CT Scan

- We cannot support using the presence of free fluid as a trigger for mandatory celiotomy after blunt abdominal trauma. — Livingston et al., 1998.
- The presence of more than trace amounts of free fluid without solid organ injury in patients with blunt trauma is a strong indication for celiotomy. — Birdsell et al., 1998.
- Intra-abdominal fluid as the sole finding on abdominal CT scan does not mandate immediate celiotomy in the bluntly injured pediatric patient. — Hulka et al., 1998.
- The finding of free fluid in the absence of solid organ injury in blunt abdominal trauma is associated with a high rate of clinically significant visceral injury. Mandatory exploratory laparotomy is recommended. — Ng et al., 2000.

Physiologic Intraperitoneal Fluid

- Small quantities of physiologic intraperitoneal fluid seen in both males and females.
- Free fluid is the most sensitive sign of bowel injury.
- Predictors of a "benign" cause for "free" fluid:
  - Isolated to pelvis (pelvic, below 3rd sacral segment).
  - Low density (< 15 HU).
  - Small quantity (≤ 2.5 cm in cranio-caudal extent).
- Isolated fluid outside the pelvis, especially between the mesenteric leaves, bowel loops, or in the paracolic gutters should be treated with suspicion.
- For isolated small volumes of free "benign" pelvic fluid, observation appears safe.

Incidental Findings on CT

- 12 – 45% of abdomino-pelvic CT scans will have incidental findings.
  - Some have imaging features diagnostic of benign disease.
  - Lower rates with head and neck.
  - Higher rates (up to 45% for WBCT, most from abdomen).
  - Some have potential serious morbidity.
- Increasing incidence with increasing age.
- Majority of patients with incidental findings (75%) have no traumatic injury in abdomen or pelvis.
  - Higher chance in some studies of identifying an incidental findings (30%) vs. a traumatic abnormality (15%).

van Vuurt R et al, J Trauma 2011, Apr 29.

Potential pitfalls:
- Anxiety
- Increased healthcare costs for follow-up examinations.
- Coordination of care issues.
- Potential medico-legal liabilities ("lost to follow-up"): Focused on the primary disease process, forget about the incidental finding.
- Potential morbidity for unnecessary biopsy or surgery.
- Downstream healthcare costs.

Incidentals need to be included in comparative effectiveness studies.

Major Incidental Findings Rate and Patient Age Trauma CT Abdomen and Pelvis at Harborview

- Strong correlation between subject age and the major incidental findings rate (p < 0.0001).

Radiation Exposure from CT
Cumulative Radiation Exposure in Major Trauma Patients

- Although low-dose techniques may be used to reduce the dose of any single scan, repeat scanning increases radiation dose for major-trauma patients.
- Correlates with ISS and LOS.

<table>
<thead>
<tr>
<th>ISS</th>
<th>Radiation exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS &lt; 9</td>
<td>25 mSv</td>
</tr>
<tr>
<td>ISS 9+</td>
<td>14 mSv</td>
</tr>
<tr>
<td>Mean</td>
<td>15.5¹ – 106² mSv</td>
</tr>
</tbody>
</table>

- CT accounts for 93% of radiation exposure².

2. Kim PK et al, J Trauma. 2004 Sep;57(3):510–4
Reasons for Increased ED Utilization

1. Use of CT improves outcomes.
   - E.g. Appendicitis:
     - Harborview 1995 – 2007
       - CT utilization for appendicitis increased from 13% to 84%.
       - Negative appy rate declined from 25% to 4% (now lower.)
   
2. Use of CT in the ED leads to early discharge and saves money.
   - E.g. Minor head injury, coronary CTA, cervical spine trauma

3. “Hyposkilia”, radiologists recommending testing, medico-legal & time pressure, etc.

Ways to reduce radiation dose.

- Judicious use of CT.
- Radiologists should use lowest dose protocols that yield diagnostic quality imaging.
- Newer CT technology.
- Avoid unnecessary repeat studies.
- Non-radiation imaging techniques where appropriate.
- Institutionally track radiation doses.
- Campaigns.

Increasing Speed: Dynamic Angio

- 80 cm scan length dynamic angio.
- 70 kVp
- Low-dose
- Any part of the body.

Image: Siemens Healthcare

The future

Ultra-High speed CT and DECT
Summary

- Future CT in Trauma:
  - Potentially earlier, integrated with resuscitation.
  - Whole body CT is now the mainstay in BAT, but outcomes are not well established.
  - Newer: High speed CT and dual energy CT.
- Trend towards endovascular therapy for selected subgroups of patients.
- Need to tame the information explosion with detection of more subtle disease and incidental findings.
- Increasing concerns about radiation exposure, but there is still potential to improve appropriateness and reduce radiation dose.