Body CT: What is a Good Exam?

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DISCLOSURES

Research Support:
Siemens Healthcare

Off Label Usage
None
Overview

• “Good” exam

• Optimization for body imaging
  – organs
  – diseases
  – superfluous imaging
  – implementation

• “Diagnostic image quality”
The “Good” Exam
The “Good” Exam

• Justified
The “Good” Exam

• Justified

Benefit | Risk
The “Good” Exam

• Justified

Benefit

Risk

“An alternative way of stating [benefit] is that the risk of not performing the examination must exceed the risk of the examination.”

McCollough et al. AJR 2009
Justification

- Based on patient risk
  - Symptomatic
  - Asymptomatic
- Appropriateness
  - Compared to alternatives
- Ameliorating Factors
  - Patient co-morbidities & compliance
  - Local expertise & availability
The “Good” Exam

ACR Appropriateness Criteria®

The ACR Appropriateness Criteria® are evidence-based guidelines to assist referring physicians and other providers in making the most appropriate imaging or treatment decision for a specific clinical condition. By employing these guidelines, providers enhance quality of care and contribute to the most efficacious use of radiology.

The guidelines are developed by expert panels in diagnostic imaging, interventional radiology, and radiation oncology. Each panel includes leaders in radiology and other specialties. There are currently 167 topics with over 600 variants in the September 2009 Version.

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ACR Appropriateness Criteria® Search Engine

This search engine allows you to search for clinical conditions found within the ACR Appropriateness Criteria® documents.

Click here to use our ACR Appropriateness Criteria® Search Engine

Anytime, Anywhere™ Application for Handheld Electronic Devices

In collaboration with Singapora, the ACR has developed the Anytime, AnywhereTM application for handheld electronic devices as an alternative solution to radiology benefit management companies or computerized physician order entry systems that do not contain the ACR Appropriateness Criteria® guidance. This application provides instant, point-of-care access to all of the 167 topics, which can be directly downloaded onto the iPhone, BlackBerry, Palm, or other PDAs, smart phones, or handheld electronic devices. The content includes topics from expert panels in breast, cardio, gastrointestinal, musculoskeletal, neurology, thoracic, urology, pediatric, vascular, and women’s imaging, as well as interventional radiology and radiation oncology.

Diagnostic Imaging Topics

Topics with an asterisk (*) include pediatric imaging recommendations.

There are ten diagnostic imaging expert panels:

- Breast Imaging
- Cardiac Imaging
- Gastrointestinal Imaging
The “Good” Exam

American College of Radiology
ACR Appropriateness Criteria®

Clinical Condition: Crohn’s Disease
Variant 1:
Adult; initial presentation (abdominal pain, fever, or diarrhea); Crohn’s disease suspected.

<table>
<thead>
<tr>
<th>Radiologic Procedure</th>
<th>Rating</th>
<th>Comments</th>
<th>RRI *</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT abdomen and pelvis with contrast (CT enterography)</td>
<td>9</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>X-ray small-bowel follow-through</td>
<td>7</td>
<td></td>
<td>Med</td>
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<tr>
<td>CT abdomen and pelvis with contrast (routine)</td>
<td>6</td>
<td></td>
<td>High</td>
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<tr>
<td>X-ray contrast enema</td>
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<tr>
<td>MRI abdomen and pelvis with contrast (MR enterography)</td>
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<tr>
<td>X-ray abdomen</td>
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<tr>
<td>US abdomen and pelvis</td>
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<tr>
<td>US pelvis endorectal</td>
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<td>Tc-99m HMPAO leukoscinintigraphy</td>
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</table>

Rating Scale: 1=Least appropriate, 9=Most appropriate

Not linked with suggested acquisition protocols

Summary of Literature Review

Crohn’s disease (CD) is a chronic inflammatory disease involving the gastrointestinal tract. The etiology is unknown, but evidence suggests that a genetic predisposition combined with an abnormal interaction between the gut and enteric microorganisms may play a role in the pathogenesis. Patients usually present with the
The “Good” Exam

• Justified

• Optimized

Use doses that are as low as reasonably achievable (ALARA) without compromising diagnostic task.
The “Good” Exam

• Justified
• Optimized

Use doses that are as low as reasonably achievable (ALARA) without compromising diagnostic task.

Adapts CT acquisition to patient and disease
The “Good” Exam

- Justified

- Optimized

Considers many other factors other than radiation dose
- type, rate of IV contrast, phase of enhancement
- type, amount & timing of enteric contrast
- alternative modalities
- patient-specific factors
Optimization

Maximizing disease detection while minimizing dose and non-radiation risk

• CT acquisition parameters that affect
  – spatial & temporal resolution, contrast/noise, timing
• Patient preparation - oral and intravenous contrast delivery
• Visual assessment of critical structures & relevant CT data
  – radiologist review
  – image reconstruction & post-processing (3D, 2D MPR, DE)
Optimization

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# Optimization of CT Acquisition

<table>
<thead>
<tr>
<th>Disease/Patient Consideration</th>
<th>Parameters Under User Control</th>
</tr>
</thead>
</table>

Technology Assessment Institute: Summit on CT Dose
Optimization of CT Acquisition

Disease/Patient Consideration
- Size of index pathology
- Temporal importance of enhancement, # phases
- Contrast (lesion-to-background)
- Organ
- Size of patient
- Lesion depiction
- Consequence of false negative

Parameters Under User Control
- Collimation, slice thickness
- Table speed, heat capacity of tube, collimation, scanner
- Oral & IV contrast, rate of injection, kV
- Tube current, slice thickness
- Slice thickness, tube rotation, kV, generator power, scanner
- Image reconstruction & post-processing, dual energy
- Dose, image reconstruction
Slice Thickness
Slice Thickness

- Survey or follow-up – 5 mm
- Liver, pancreas, bowel - ≤ 3 mm
**Slice Thickness and Dose**

- Dose reduction possible with thin slices when a lot of contrast defines lesion
  - Colonography
  - Enterography
  - Renal stone
Low Dose Renal Stone CT

Indications

- Known stone disease + prior CT
- Pts with symptoms highly suspicious for ureteral stone (i.e., acute renal colic)
- Pregnant patients with equivocal US results (US is 1st line imaging test)
- Pre-contrast imaging for CT Urography
- Exclusions - > 50 cm or metal
- Drop QRM from 240 to 100 mAs
155 lbs (71 kg)

11-06-06
100 effective mAs

10-23-06
240 effective mAs
Dose reduction not a good idea for subtle tumors in complex, solid organs
- Pancreas
- Liver

Our dose settings are about 30% higher in liver and pancreas CA
Phase of Enhancement

Portal Phase

Pancreatic Phase (lower kV)
Phases of Enhancement

- Early arterial
- Late arterial
- Pancreatic
- Enteric
- Portal
- Delayed

Designed to maximize organ or tumor enhancement

- Arteries & Tumor Blush
- Maximal organ enhancement
- Tumor Washout & GU
**Phases of Enhancement**

Designed to maximize organ or tumor enhancement

- **Early arterial**
- **Late arterial**
- **Pancreatic**
- **Enteric**
- **Portal**
- **Delayed**

- Bolus-triggered, 15 – 20 s – CTA, HHT, islet cell
- 18 sec post trigger, 35 s
  - HCC
- 20 sec post trigger, 45 s
  - Max panc to tumor, p ACA
- 20 sec post trigger, 50 s
  - Max bowel enhancement, Crohn’s
- 40 sec post trigger, 65 – 70 s
  - Portal + HV opacified, workhorse
- 3 – 5 minutes
  - Tumor washout, Urothelium
Phases of Enhancement

- Liver – arterial (early or late), portal, delayed
- Pancreas – pancreatic, portal
  - Use both for first time tumor and pancreatitis
  - Pancreatitis f/u with single phase
- Kidney – CM(30), Arterial (45), Nephrographic (90-100), Delayed
- Small bowel – enteric, ± arterial, ± delayed
  - Multiphase scanning – mesenteric ischemia, occult GI blood loss
- Colon – portal or enteric
Spatial & Temporal Resolution Increase Benefit
Common Tumor Rule Outs

- Liver – R/O HCC
  - Higher dose
  - 2 – 3 mm slice
  - Late arterial (tumor blush), portal, delayed phase (tumor washout)
  - Axial + coronal

- Pancreas – R/O pancreatic adenocarcinoma
  - Higher dose
  - 2 - 3 mm slice (pancreatic duct)
  - Pancreatic (tumor detection), portal (veins & liver)
  - Axial + coronal
Optimization of CT Acquisition

Disease/Patient Consideration
- Size of index pathology
- Temporal importance of enhancement, # phases
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- Organ
- Size of patient
- Lesion depiction
- Consequence of false negative

Parameters Under User Control
- Collimation, slice thickness
- Table speed, heat capacity of tube, collimation, scanner
- Oral & IV contrast, kV
- Tube current, slice thickness
- Slice thickness, tube rotation, kV, generator power, scanner
- Image reconstruction & post-processing, dual energy
- Dose, image reconstruction
Size of the Patient

Technique should *always* be adapted to patient size

- Minimize dose
- Maximize contrast (\(?kV\), oral and IV) and image quality
Adapting for Smaller Patients

- AEC
- Technique charts
- kV selection
- Decreased dye load
- Oral Contrast
Morbidly Obese Imaging

Problems

• Image quality (artifacts, CT number)
• Time of scan > breathhold, multiphase timing
• Heat capacity
• FOV
• Table limit
Morbidly Obese Imaging

Problems

- Image quality (artifacts, CT number)
- Time of scan > breathhold, multiphase timing
- Heat capacity
- FOV
- Table limit

Select the “obese” scanner for your practice based on table limit > generator power > FOV > # tubes
Morbidly Obese Imaging

Problems

- Image quality (artifacts, CT number)
- Time of scan > breathhold, multiphase timing
- Heat capacity
- FOV
- Table limit

• Increase mAs at 120 kV (slow table speed)
• Choose a thicker detector width (e.g., 24 x 1.2 mm) & slice thickness
• Increase tube energy to 140 kV
• Employ dual source, if possible
• Slow rotation time to 1 rot/s
Optimization

Maximizing disease detection while minimizing dose and non-radiation risk

- CT acquisition parameters that affect
  - spatial & temporal resolution, contrast/noise, timing
- Patient preparation - oral and intravenous contrast delivery
- Visual assessment of critical structures & relevant CT data
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  - image reconstruction & post-processing (3D, 2D MPR, DE)
Oral and Intravenous Contrast Increase Benefit
Individualization of Patient Prep

Parameters to Consider

- Iodinated contrast (type, injection rate/delivery)
- Enteric contrast
- Bowel prep and tagging

Disease/Patient Consideration

- Organ, temporal enhancement
- Lesion-to-background contrast differences
- Need for bowel distension & volume challenge
- Colonography
**Iodinated IV Contrast**

- Highly idiosyncratic
- Concentration and rate of injection affect enhancement

<table>
<thead>
<tr>
<th>Injection Rate (cc/s)</th>
<th>Pancreatic Phase (sec)</th>
<th>Portal Phase (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>45</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
<td>65</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>60</td>
</tr>
</tbody>
</table>

- Fixed amount/rate vs. weight-based/fixed injection duration, blended
Oral Contrast Agents

- Positive oral contrast agents – ca, screen
  - Barium or iodine
- Neutral agents – SB, CTA
  - Water, PEG, Volumen (sorbitol)

Young BM, et al. JCAT 2008
Oral Contrast Agents

- Administration
  - Amount
  - Timing of aliquots
  - Timing of scan
  - Bathrooms

Young BM, et al. JCAT 2008
Oral Contrast Agents

- Positive ~ 500 x 2, 20 min apart
- Neutral ~ 500 x 3 + 500 water, 15 minutes apart

Young BM, et al. JCAT 2008
Optimization

Maximizing disease detection while minimizing dose and non-radiation risk

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Individualization of Visual Evaluation

Disease/Patient Consideration

• Will two planes increase conspicuity?
• ? 3D structure with large contrast differences
• Will material classification assist in diagnosis?
• Are the images too noisy?

Review/Recon/Processing

• Automatic 2D MPR’s
• Interactive 3D (angio, colon)
• Dual energy processing
• Noise reduction methods
Coronal Images Increase Confidence

Courtesy Dr. Jim Huprich
Don’t Give Me Any Coronal Image!

Axial

Coronal
Image reconstruction and post-processing improve benefit
Optimization

Superfluous Series

Easiest way to minimize dose without affecting diagnostic accuracy is to eliminate phases that do not contribute to diagnosis
Optimization

Superfluous Series

Non-contrast series in multiphase exam

- Useful for renal stones, initial pancreatitis (CBD stone)
- Generally not useful
  - Multiphase liver imaging*
  - F/U pancreatitis
  - Pancreatic mass evaluation

Optimization

Superfluous Series

Delayed series in multiphase exam

• Useful for
  – urothelial neoplasm
  – Tumor “washout” – HCC, RCC
  – Post-op GU

• Generally unhelpful

• Appropriateness guidelines often comment
Optimization

Follow-up Exams

• Renal stone protocol – low dose
• Pancreatitis - single phase
• Other tumors – single phase
Optimization

Maximizing disease detection while minimizing dose and non-radiation risk

- CT acquisition parameters that affect:
  - spatial & temporal resolution, contrast/noise, timing
- Patient preparation:
  - oral and intravenous contrast delivery
- Visual assessment of critical structures & relevant CT data:
  - radiologist review
  - image reconstruction & post-processing (3D, 2D MPR, DE)

Impact of acquisition and visual assessment modifies both risk and benefit.
Individualization
Individualization

Your Scanner and Allied Health Staff
# Technology Assessment Institute: Summit on CT Dose

## Abdominal Protocols

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<tr>
<th>Protocol</th>
</tr>
</thead>
<tbody>
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<td>Abdomen &amp; Pelvis – Routine</td>
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<tr>
<td>Adrenals – Targeted/Thin</td>
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<tr>
<td>Colonography – Routine &amp; Failed Colonoscopy</td>
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<tr>
<td>Colonography – w/ Contrast for Colorectal Lesion</td>
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<td>Cystogram</td>
</tr>
<tr>
<td>Enteroclysis – with Neutral Enteric Contrast</td>
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<tr>
<td>Enterography (Single Phase)</td>
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<tr>
<td>Enterography LD (Single Phase)</td>
</tr>
<tr>
<td>Enterography (Bi-Phase) – For Mesenteric Ischemia</td>
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<tr>
<td>Enterography (Tri-Phase) – For GI Bleeding</td>
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<tr>
<td>Esophageal Cancer Staging</td>
</tr>
<tr>
<td>Kidney – Triphase – Renal Mass, Pre &amp; Initial Post Ablation, and Partial Nephrectomy</td>
</tr>
<tr>
<td>Kidney Biphase – FU RCC Radical Nephrectomy, 2nd Post Ablation, and Partial Nephrectomy</td>
</tr>
<tr>
<td>Kidney – (CTA and Venous) Pre Op Vascular Mapping</td>
</tr>
<tr>
<td>Kidney – Renal Stone</td>
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<tr>
<td>Kidney – Renal Stone Composition (DE)</td>
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<tr>
<td>Kidney – Renal Stone, Low Dose</td>
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<tr>
<td>Kidney – Renal Stone Quantification</td>
</tr>
<tr>
<td>Liver – Bi-Phase</td>
</tr>
<tr>
<td>Liver – Cholangiogram (Siemens)</td>
</tr>
<tr>
<td>Liver – Tri-Phase for Cirrhosis, HCC, and Hepatoma</td>
</tr>
<tr>
<td>Liver – HHT</td>
</tr>
<tr>
<td>Liver – Living Donor (Pre-Op) (Siemens)</td>
</tr>
<tr>
<td>Liver – Living Donor (Post-Op) (Siemens)</td>
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<tr>
<td>Liver – Post-Ablation</td>
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<tr>
<td>Liver – Pre-Ablation</td>
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<tr>
<td>Liver – Volumetric Pre hepatic</td>
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<td>Pancreas – Acute Pancreatitis</td>
</tr>
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<td>Pancreas – Bi-Phase</td>
</tr>
<tr>
<td>Pancreas – Bi-Phase w/ 3D Pancreatogram</td>
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<td>Pancreas – Tri-Phase for Islet Cell</td>
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<td>Pancreas – Single Phase for Follow Up</td>
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<tr>
<td>Prostate – Seed (Pre and Post Implant)</td>
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<td>Prostate – Seed (Placement)</td>
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<tr>
<td>CTU/CTA - Renal Donor</td>
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<tr>
<td>CTU – Type I</td>
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<td>CTU – Type II</td>
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<td>CTU – Type III</td>
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<td>CTU – Type IV</td>
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<td>CTU – Type V</td>
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<tr>
<td><strong>ABDOMINAL PROTOCOLS</strong></td>
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</table>
## ENTEROGRAPHY SINGLE PHASE PROTOCOLS

### STANDARD ADULT (06_1)
- **GE**: 8, 16 (3M), 16 (4C), 64
- **Siemens**: 16, 40, 64, Def-64, Def-AS+, F-128

### PEDIATRIC (02_0)
- Siemens: Def-64, F-128 (For patients 22-45 kg)
- Siemens FLASH Mode: F-128 (For patients 22-45 kg)

### DUAL SOURCE (DS06_1)
- Siemens (80/80): Def-DS
- Siemens (100/100): F-128

### DUAL ENERGY (DE06_1)
- Siemens: Def-DE

---

## ENTEROGRAPHY-TRIPHASE GI BLEEDING

### STANDARD ADULT (06_2)
- **GE**: 64
- **Siemens**: 64, Def-64, Def-AS+, F-128

### DUAL SOURCE (DS06_2)
- Siemens (80/80): Def-64
- Siemens (100/100): Def-64
- Siemens (120/120): Def-64

**Patients with a lateral width of less than 32 cm and who cannot have a full colon cleansing.**

**Patients with a lateral width of 32-42 cm and who cannot have a full colon cleansing.**

### DUAL ENERGY (DE06_2)
- Siemens (100/140s): F-128

---

**Scheduling**
ENTEROGRAPHY SINGLE PHASE
(With out Blood loss)

GENERAL:
Indications include, but are not limited to, Crohn’s and Sprue. Patients will be arriving 75 min. before their appointment time.

CONTRAST:
Oral: IV must be in place BEFORE the patient is given oral contrast. Nurse will give the following oral contrast to the patient:

<table>
<thead>
<tr>
<th>Routine Patient</th>
<th>ER Patient</th>
</tr>
</thead>
<tbody>
<tr>
<td>450mL Volume, 60 min prior to CT</td>
<td>1.8-2.0 liters of water over 30min.</td>
</tr>
<tr>
<td>450mL Volume, 45 min prior to CT</td>
<td>Scan the patient 75min after the start of drinking water.</td>
</tr>
<tr>
<td>450 mL Volume, 30 min prior to CT</td>
<td></td>
</tr>
<tr>
<td>500 mL or 2 glasses of water, 15 min prior to CT</td>
<td></td>
</tr>
</tbody>
</table>

IV: Use **weight-based chart**. Standard is 150ml Omnipaque 300 at 4cc/sec.

For **large patients** consult with radiologist regarding increasing contrast dosage. Consult with radiologist regarding use of Reglan.

**Good coordination is critical for this timed study.**

TOPOGRAM: PA. 512. **STOP SCAN** when through pelvis.

**INFORM THE RADIOLOGIST IF ANY RESIDUAL BARIUM ON THE SCOUT/TOPOGRAM.**

IF PATIENTS ARE: <45CM please use 2 mm x 1 mm slice thickness and increment.
IF PATIENTS ARE: >45 CM please use 3x2 slice thickness and increment.
If B43 is not available please use the B40 kernel.

ENTEROGRAPHY:
Scan from top of liver through Perineum. Do in one breath-hold (patient can breathe out slowly if necessary).

<table>
<thead>
<tr>
<th>Siemens</th>
<th>Sens-16</th>
<th>Sens-40</th>
<th>Sens-64</th>
<th>Def-64</th>
<th>Def-AS+</th>
<th>F-128</th>
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<tr>
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<td>Feed (mm/rot)</td>
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<td>Prep Delay (s)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
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<td>50</td>
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<tr>
<td>Min. Retro (mm)</td>
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<td>0.6</td>
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<td>CTDI (mGy)</td>
<td>19</td>
<td>21.72</td>
<td>18</td>
<td>18</td>
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<td>16.19</td>
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<td>Base Protocol</td>
<td>Abd Routine</td>
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</tr>
</tbody>
</table>
Individualization

Requires Planning by Integrated Team
MD’s, PhD’s, RT’s, RN’s
What is “diagnostic image quality”?

“I know it when I see it.”

Justice Potter Stewart
U.S. Supreme Court
What is “diagnostic image quality”? 

- Often graded on a 5 – point scale 
  - Definitions vary 
  - Reproducibility often “good” 
- Sometimes accompanied by 
  - Other subjective scales such as 
    - Artifact scores 
    - Diagnostic confidence scores 
    - *Subjective Sharpness, Conspicuity, Noise ± Noise texture* 
  - Objective measures 
    - Noise & contrast measurements 
    - *Gradient sharpness*
What is “diagnostic image quality”? 

European Guidelines on Quality Criteria for CT* 

- Visualization of critical structures
- Visually sharp reproduction of structures (small vessels and lymph nodes, vascular/organ edges)
- Acquisition: CTDI vol 35 mGy; nominal slice thickness 7–10 mm; 3–5 mm “small lesions”
- Subjective Noise**: the 3 bears 

1 = too little noise  
2 = just right, optimum noise  
3 = too much noise affecting interpretation

**http://www.drs.dk/guidelines/ct/quality/htmlindex.htm  
** Prakash, Kalra et al. Invest Radiol 2010; 45: 202–210
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- Acquisition: $\text{CTDI}_{\text{vol}}$ 35 mGy; nominal slice thickness 7 – 10 mm; 3 - 5 mm “small lesions”
- Subjective Noise**: the 3 bears
- Diagnostic Confidence**: 4-point scale

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European Guidelines on Quality Criteria for CT*

• Great start

• Weaknesses
  – Too forgiving
  – Objective measures of sharpness, noise texture, low contrast conspicuity
  – Subjective measures of noise texture & conspicuity
  – Common image datasets

• Similar AAPM guidelines would be a boon to development, evaluation and validation of noise reduction technologies

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http://www.drs.dk/guidelines/ct/quality/htmlindex.htm
Getting a “Good Exam”

Example Patient Profile

28 yo with Peutz-Jehgers

Looking for large/dysplastic small bowel polyps
Getting a “Good Exam”

Example Patient Profile

- Small bowel “filling defect”
- Enhancement only important if IV contrast
- Bowel distention important
- Young patient likely to undergo multiple exams

- CT enteroclysis > CT enterography
- Positive oral contrast
- Minimal collimation < 1 mm, coronal recon; 2 mm axial slices
- Half-standard tube current
Conclusions

• CT imaging benefits patients

• *Net benefit* affected by
  – *Patient risk, appropriateness*
  – *Optimization of CT technique*

• Benefit maximized by individual consideration
  – *Protocol development incorporating CT acquisition, pt prep, visualization*
  – *Continuing commitment*
Suggested readings

- ACR Appropriateness Criteria
  - [http://www.acr.org/secondarymainmenucategories/quality_safety/app_criteria.aspx](http://www.acr.org/secondarymainmenucategories/quality_safety/app_criteria.aspx)

- European Guidelines on Quality Criteria for CT
  - [http://www.drs.dk/guidelines/ct/quality/Preamble1.htm](http://www.drs.dk/guidelines/ct/quality/Preamble1.htm)

- ACR White Paper on Radiation Dose in Medicine
  - Amis ES et al. JACR 2007; 4: 272 – 284

- In Defense of Body CT
13 months prior


Led to diagnosis

Gangi et al. AJR 2004

Careful radiologist review improves benefit
Careful radiologist review improves benefit
Enteroclysis – with Neutral Enteric Contrast

Enteroclysis – with Positive Enteric Contrast

Enterography (Single Phase)

Enterography LD (Single Phase)

Enterography (Bi-Phase) – For Mesenteric Ischemia

Enterography (Tri-Phase) – For GI Bleeding

Low-grade obstruction

Polyposis, obstruction

Crohn’s, sprue, diarrhea

Ischemia

Occult GI blood loss