Neuro CT – What’s a Good Head Exam?

Rajiv Gupta, PhD, MD

Neuroradiology
Massachusetts General Hospital
Harvard Medical School
Outline

• What we need to see?
• Routine Head CT protocols
• Dose optimization strategies
• Some newer tricks using Dual Energy CT
58 year old, new onset of neurologic symptoms

Where is the Abnormality?

CT: Equivocal for an infarct
Acute Infarct in the ACA territory

CT Angiography

CTA SI: Reduced perfusion

DWI
Requirements

• Good gray-white differentiation
Different Case: Young patient after trauma
Requirements

- Good gray-white differentiation
- Proper cupping correction
11 month old female that presented with gagging after trauma to oropharynx with drum stick.
Diagnosis

• Retropharyngeal abscess
  – Etiology
    • Suppurative bacterial lymphadenitis
      – S. aureus, Strep B, oral flora
    • Foreign body perforation
    • Trauma
Requirements

- Good gray-white differentiation
- Proper cupping correction
- Good soft tissue discrimination
44 year old fell from a tree
2 months later
Surgical Specimen

Take-home Points:
- Wood may appear as air
- Accurate HU calibration is important
Another Case: Pencil vs Globe
Requirements

- Good gray-white differentiation
- Proper cupping correction
- Good soft tissue discrimination
- Accurate, reliable HU calibration
History of Trauma

Subtle right occipital fracture, only visible on thin slices, and sharp kernel
Requirements

- Good gray-white differentiation
- Proper cupping correction
- Good soft tissue discrimination
- Accurate, reliable HU calibration
- High spatial resolution and MTF
4 year old with 2 week history of headaches, abdominal pain, anorexia and vomiting. Recent antibiotics for sinusitis.

Artifact or Pathology?
Imaging 1 Week Later

CT w/ Contrast

T1 Post
Pathology: Burkitt Lymphoma

B-cell lymphoma
Requirements

- Good gray-white differentiation
- Proper cupping correction
- Good soft tissue discrimination
- Accurate, reliable HU calibration
- High spatial resolution and MTF
- Artifact-free posterior fossa and skull base
“The Chest X-ray of the Brain”

Must support quick, confident read

Main Culprits

- Poor SNR
- Poor CNR
- Poor spatial resolution
  - Improper recon kernel
  - Improper protocol
- Artifacts
  - Motion
  - Scatter
  - Beam hardening
  - Windmill
  - …
CT Artifacts

- **Motion:**
  - Recon assumes a stationary object
  - Problem in Pedi patients
  - Make scanners faster
    - 0.28 sec rotation
    - FLASH scanner

- **Scatter:**
  - Blurs the image
  - Lowers $\mu$-effective
  - Scatter-to-primary ratio high behind bones
  - Scatter and beam hardening in same area
**Beam Hardening**

- Effective beam energy increases.
- Beam “hardens” as it penetrates. \( \mu \)
- Higher \( E \) => lower \( \mu \).
- “Cupping artifact”
Windmill artifact
**Windmill artifact**

- Low pitch, overlap helices
  - Optimal ~ 0.5 - 0.66
- Minimal possible table feed
- Maximal gantry rotation speed
- Thick reconstructions
  - 1.25 by 0.625 mm
- Small focal spot
  - mA limited?
### Sample MGH 64-slice Head CT Protocol

**Technology Assessment Institute: Summit on CT Dose**

**Sample MGH 64-slice Head CT Protocol**  
*(Minor Variations between Scanners)*

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Recon 2:  
5 MM DX STD AXIALS

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<tr>
<td>DFOV</td>
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Reformat:  
Coronal Skull Auto w/DMPR

DFOV 22
Thickness 5.0
Interval 2.5
Window Head

Recon 3:  
2.5 MM DX BONE AXIALS

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DECRAH CODE:  
CTBR-  
Send dose report to PACS
CT Dose Reduction Strategies

- Use another modality!
- Optimize acquisition
  - Tailor to clinical requisition
  - Lower technique
  - Minimize artifacts
  - Dual Energy acquisition
- Optimize reconstruction / post-processing
  - FBP vs newer “iterative reconstruction” kernels
  - Filters, e.g. metal streak reduction
- Optimize readout
  - Coronal Reformats
  - Optimal PACS display
  - Appropriate window/level settings

Michael Lev, MGH
Optimizing Scan Parameters: Basic Principles

• Lowest possible mAs is proportional to:
  – Degree of intrinsic tissue contrast
  – Acceptable level of image noise
  – Noise ~ 1 / SQRT (mAs)

• Tailor the protocol to the clinical question
  – E.g.: 30 mAs for sinus CT, FESS planning
    *Mulkens et al, AJR May 2005*
    *Loubele et al, Radiat Prot Dosimetry 2005*
  – E.g.: 30 mAs for pituitary CT, transphenoidal sx

Michael Lev, MGH
170 mA

90 mA
50% mAs Reduction?
Slightly Noisier, but OK for F/U

- Dept wide study ↓ mA by 50% for all CT’s
  - Unchanged HU, GW conspicuity
  - 22% decreased CNR (attributable to noise)

Mullins, Lev, Bove, O’Reilly, Saini, Rhea, Thrall, Hunter, Hamberg, and Gonzalez. Comparison of image quality between conventional and low dose NCCT. AJNR Apr 2004
Optimizing Acquisition: Other Considerations

- Lower kV
  - Increased photoelectric effect
    - Higher HU iodin
- Adaptive Dose Modulation
  - Z-axis vs XY ("angular")
- Avoid rescanning same region
  - E.g., head and temporal bone, face and sinuses (? billing)
- Maximize quality parameters
  - Decrease motion artifact: speed, sedation
  - Remove extraneous hardware
  - Optimize contrast bolus; right sided
  - Angle gantry though clips, fillings

Brown, Lustrin, Lev, Taveras et al. AJR 1999
Adaptive Dose Modulation

- Varies mA with AP, lateral attenuations / diameters
- Noise index definition
  - … “approximately equal to standard deviation in the central region of the image when a uniform phantom is scanned and reconstructed”
- Substantial dose reduction for NCCT, CTA, C-spine
  - % decrease depends on baseline protocol
    *Smith, Dillon, Wintermark et al. Radiology 2008*
- More useful for neck than head, in our experience
  - Wide range of thickness in shoulders
  - Noise index values of 11.4 and 20.2, result in 20% and 34% dose reduction, respectively
    *Russell, Anzai et al, Seattle. AJNR 2008*
ASIR (GE), IRIS (Siemens):
Adaptive Statistical Iterative Recon
(MBIR --- Model Based Iterative Recon)

Improved Image Quality, Lower Dose

Courtesy of Shervin Kamalian and GE Healthcare
# Sample CT Dose Reduction at 30% ASIR

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<th>mA</th>
<th>Noise (ADM)</th>
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Single vs Dual Energy CT

- A single CT Number (HU)
- Prior knowledge for material separation
- Unable to distinguish materials with same HU
  - Blood vs. dilute contrast
  - Blood vs. diffuse mineralization
  - Uric acid vs. Ca oxalate
  - Calcification vs. gouty tophus
**Dual Energy Principles**

- Total attenuation decreases with increasing energy
- Decrease is characteristic for each material
- Depends on photon energy and material density
- X-ray absorption depends on the inner electron shells
  - DECT is sensitive to atomic number and density
  - DECT is not sensitive to chemical binding
**Dual Energy Systems**

**Siemens: Dual Source CT**
*(Definition)*

- Two X-ray sources, two detectors, simultaneous acquisition
- Operate one source at 80kV and the other at 140kV

**General Electric: Discovery Gemstone (HD-750)**

- Single Source, single detector, on a fast gantry
- Rapidly alternate the single tube between 80kV and 140kV
Dual Energy Systems: Pro and Cons

Siemens: Dual Source CT
(Definition)

• Simultaneous acquisition
• Optimized tube current
• Projections: 90 deg apart
• One detector smaller than other

80kV  140kV

General Electric: Discovery Gemstone (HD-750)

• Projections close to each other in time => separation in projection domain
• Tube current constant (i.e., not optimized for each kV).
Application: Bone Removal

- Automatic bone removal without user interaction
- Intended use: base of the skull, carotids, runoffs

Courtesy of University Hospital of Munich - Grosshadern / Munich, Germany
Application: Calcified Plaque

- Automatic bone removal without user interaction
- Calcified plaques can be identified and „switched on and off“

Courtesy of University Hospital of Munich - Grosshadern / Munich, Germany
Application: Kidney Stones

- Uric acid stones can be differentiated from other renal calculi.
Application: Gout

Dual Energy

Single Energy

T1W MRI

Gout Patient

Healthy Control

Hyon K. Choi, Beth Israel Deaconess Boston
Ultra-Low Dose Spectral CT Angiography

- Uses 0.625mm and 1.25mm slices from 12 sec helical study
- Excellent IQ with ultra-low dose (14 mA) and low 50ml iodine injection

Images courtesy of GE and Rabin Medical Center, Israel
Posterior Fossa Beam Hardening Reduction

80kVp | 140kVp | 100keV

Xtream HD Console and GE LightSpeed Evaluation System

Courtesy of Dr. Amy Hara, Mayo Clinic Arizona
A Clinical Case

- 78 yo woman, acute onset of left hemiparesia
- MRI:
  - Right sub-insular infarct
  - Clot in the M1 segment of right MCA.
- Catheter-directed, intra-arterial embolectomy
- Post-procedure CT: Intracranial hyper-density
- Question: Is it contrast staining or hemorrhagic conversion of infarct?
Pre-procedure CT (single energy)

Initial Head CT: Hyperdensity in distal M1
Post-procedure single energy CT

Contrast staining or hemorrhagic conversion?
Question: Is it blood or contrast staining?
**DECT Material Separation**

**Iodine Overlay**

**Virtual non-contrast Image**

Contrast staining of infarct (ie, not blood)
**MGH Head CT Take Home Points**

- **Dose well below ACR guidelines**
- **Configure protocol to the clinical need**
- **Avoid orbits if possible**
  - Especially important in serial scans: ICU, pediatrics
  - *But don’t* sacrifice diagnostic accuracy!
- **Pediatrics**
  - 125 mA used, < HALF the adult dose
  - Strategy: *screen* with low dose CT, *confirm* with MRI
  - Age < 18
- **Axial vs helical mode?**
  - Axial, arguably, has > SNR for otherwise fixed settings
  - No real speed advantage to helical
  - Helical = more reformat/recon options (e.g., coronals)
- **Dual Energy CT**
  - Effective tool for material discrimination
  - Quantitative tool
  - Both sensitive and specific for Hemorrhage vs. Iodine
  - Limited by saturation and other artifacts