HOW LOW CAN YOU GO?
A BASIC GUIDE TO CT DOSE REDUCTION

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Disclosures

• I will discuss specific vendors, though none of them are paying me.
Disclosures
Outline

• Basic physics of dose reduction
  • How radiation is measured

• Parameters radiologists can adjust
  • mAs
  • Kvp
  • Iterative reconstruction
  • Limit scan “creep” and phase “creep”

• Some “real world” examples

• Questions
LIMBO

PARTY

"IVY" PETE and his LIMBOMANIAOS
How is CT radiation measured:

- **CTDIvol:**
  - CT dose index
  - Units: milligrays (mGy)
  - Measure of intensity of radiation directed at the patient at a given volume
  - Measured using 16 or 32 cm phantoms.
  - Method for calculating CTDIvol is standardized across vendors

- **DLP:**
  - Dose Length product
  - Units: milligray-centimetres (mGy-cm)
  - Represents the CTDI applied to the total length of scan, thus would represent exposure to patient for the whole study.

- **Effective dose:**
  - Multiplies the DLP by a conversion factor
  - Units: milliseiverts (mSv)
  - Allows comparison of radiation exposure from different sources (xray, nuc med)
How can a radiologist reduce dose: mAs:
Time current-time product

- Reduction in milliampere-seconds (mAs) means reducing the total number of photons required to make a CT image
- mAs represents both the tube current and the time in which is turned on
- This is possibly the most common method of dose reduction
- Dose decreases linearly with mAs i.e. increase of mAs from 100→200mAs will double the scanner output and hence double the exposure to the patient
mAs

- Tube current modulation:
  - Essentially dose is reduced by modulating the tube current in respect to patient size both in the x/y planes but as well as head to toe
  - i.e. GE: Auto mA, Siemens: CareDose
  - Can reduce dose up to 40%
  - Though primary role is ensuring consistent image quality in a large volume scan.
How can a radiologist reduce dose: kVp

- Tube voltage: xray tube potential, indicates peak energy of the photons generated
- Relationship to dose is nonlinear
- Dose changes proportional to the square of the kVp
kVp

Graph showing the mass attenuation coefficient of sodium iodide as a function of X-ray energy (keV) for different attenuation processes: Total, Compton, PE, and Coherent.
**kVp**

- Due to K-edge of iodine present at 33.3 KeV, lower kVp selections will have more photoelectric effect and thus iodine will appear more attenuating at 80 kVp vs 100 kVp.
- Thus contrast resolution can improve.
- Drawback: image noise also increases as kVp is decreased.
kVp

- Reducing tube voltage reduces mean photon energy
  - Dose proportional square of kVp
  - 120 to 100 kVp reduces dose 40%
  - 120 to 80 kVp reduces dose by 70%

120 kVp
Most Studies

120 kVp
BMI > 30

100 kVp
Low BMI

100 kVp
BMI < 30

80 kVp
Children

Jacobs Eur Radiol 2003
Hohl Eur Radiol 2005
Mayo-Smith Radiol 2014
kVp

- Generally kVp are chosen based on patient size/BMI. Current scanners cannot modulate kVp during a single scan thus a single tube voltage must be decided upon prior to imaging
- Many scanners have tube voltage assist technology to help select an appropriate kVp based on patient size, age and study type
Lowering kVp

% Dose

120 kV
-44%

100 kV

80 kV
-77%*

Source: FRC Database n=3212
How can a radiologist reduce dose: Avoid Scan and Phase Creep

Scan creep
Look to limit z-axis coverage to include only anatomic areas felt relevant to the study in question.
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Scan creep
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Dose reduced by 1/3
Avoid Scan and Phase Creep

- Phase creep
  - Ensure the number of phases (i.e. noncontrast, arterial, portal venous, delayed phase) are kept to a minimum to answer the clinical question
  - Consider combining phases i.e. combined nephrographic and excretory phases for workup of hematuria
- Consider dual energy and virtual noncontrast imaging?
**Kidney and Urinary Tract Imaging:** Triple-Bolus Multidetector CT Urography as a One-Stop Shop—Protocol Design, Opacification, and Image Quality Analysis

**Purpose:** To retrospectively evaluate renal, vascular, and urinary tract visualization following a single postcontrast multidetector computed tomographic (CT) nephrographic sequence performed with three divided-volume bolus injections.

**Materials and Methods:** The Institutional Review Board approved this retrospective study. Patient informed consent was waived. Triple-
Non-contrast

Material Suppressed Iodine (Virtual Noncontrast)
Iterative Reconstruction

• Iterative:
  • The action or a process of iterating or repeating as: a. a procedure in which repetition of a sequence of operations yields results successively closer to a desired result

• Reconstruction:
  • The act or process of building something that was damaged or destroyed again

Merriam-Webster 2015.
Why has IR become such a big deal in the last 10 years?

- IR techniques have been used for decades in nuclear medicine imaging
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Why not with CT?
Why has IR become such a big deal in the last 10 years?

- Filter back projection allowed (FBP) a more simple method to reconstruct CT images:
  - FBP allow creation of images quickly, avoiding the need for substantial computing power
  - The computational processing capabilities to quickly reconstruct IR based CT images simply did not exist in a feasible form until relatively recently
  - In 2008 iterative reconstruction algorithms became commercially available for CT imaging (nearly 40 years after the first clinical CT was performed)
Why has IR become such a big deal in the last 10 years?

Introduction of IR for CT

Introduction of clinical CT

64 slice CT, cardiac CT hits market

Dual-Core Itanium 2

Pentium 4

Pentium

386

Intel CPU Trends

(sources: Intel, Wikipedia, K. Olukotun)
Why has IR become such a big deal in the last 10 years?
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General Principles of IR

• FBP methods and assumptions
• Image Noise
• “Generic Iterative reconstruction”
General Principles of IR

• FBP methods and assumptions:
  • Filtered back projection (FBP)
  • Intensities determined by photon detection described as an integral function for a specific:
    • A. tube angle
    • B. Shift in position of the x-ray tube.
  • Reconstruction process for FBP requires solving the subsequent integral equation by inversion or so called “back projection”
General Principles of IR

• FBP methods and assumptions:
  • In order to allow quick and noncomputationally complex image reconstruction FBP had to make a number of assumptions:
    • The x-ray source is a single point in space
    • The x-ray beam is pencil thin
    • The x-ray source is aligned in a fashion parallel to the x-ray detector
    • The x-ray detector is a single point in space
Filter Back Projection:

- Theoretical point source
- Theoretical point voxel
- Theoretical detector point

With each assumption noise is introduced. The basis of iterative reconstruction tools attempt to mitigate such assumptions.

Courtesy GE Healthcare
General Principles of IR

• Image Noise
  • Generally a balance between radiation dose and image noise determines scan parameters
  • The problem was prior to IR tools lowering image could only* be achieved at the expense of increased radiation dose
  • *"image based de-noising" can be performed on FBP datasets through smoothing algorithms and convolution kernels but would result in compromised spatial resolution.
General Principles of IR

- Noise Index*, Quality reference mAs* etc
  - Parameters that can be set on a CT scanner describing the level of noise in acquired CT images.
  - By altering these parameters one can indirectly alter radiation dose
  - Thus IR tools are actually noise reduction tools which allow us to scan at lower radiation doses, but create images of diagnostic quality
General Principles

• IR allows one to set the scanners noise index* such that radiation dose will be diminished and the dataset can be “saved” with application of IR.
Iterative Reconstruction Image

3.6 mSv – Noise index set at 25

FBP Image

6.2 mSv – Noise index set at 21
General Principles

• The basis of the success of iterative reconstruction techniques relies on successful modeling of CT acquisition:

• Depending on the vendor different weighting is placed on the various ways data acquisition can be modelled:
  • Systems modelling
  • Optics modelling
  • Statistical modelling
Iterative Reconstruction: closer to the real scanner model

- Theoretical point source
- Theoretical point voxel
- Theoretical detector point
- Real source
- Real voxel
- Real detector

Courtesy GE Healthcare
Vendor Specific IR Methods

- **General Electric Healthcare:**
  - **ASiR:** Adaptive Statistical Iterative Reconstruction:
    - Introduced in 2008
    - Operates in the raw data domain
    - Uses FBP images as a building block: Hybrid IR tool: allows blending of IR and FBP at 10% increments
  - **Veo:**
    - A form of MBIR: model based iterative reconstruction
    - In addition to the statistical modelling of ASiR, Veo introduces the use of modeling of system optics
  - **ASiR-V:**
    - Latest version of IR from GE as of 2015
    - More emphasis placed on object and physics modeling
    - The reduced focus on system optics modelling allows quicker reconstruction times
Images Courtesy Dr. Ricardo Cury. Baptist Hospital, Miami. a. FBP, b. 40% ASIR
Vendor Specific IR Methods

- Philips Healthcare:
  - iDose4:
    - Operates both in raw and imaging data domains
    - A process of image creation utilizing an iterative diffusion process allows images of reduced noise to be created without some of the artificial “plastic-like” appearances often associated with IR images
  - IMR: Iterative model reconstruction
Siemens Healthcare

- **IRIS: Iterative Reconstruction in Image Space**
  - Introduced in 2008
  - Image domain iterative reconstruction technique
  - Initial image created from raw data, with multiple iterations of the IR algorithm utilized to diminish noise

- **SAFIRE: Sinogram Affirmed Iterative Reconstruction**
  - Operates in raw data space
  - Utilizes FBP as a base
  - A number of “levels” are available, time efficient: taking only minutes to reconstruct entire data sets

- **ADMIRE: Advanced Model Iterative Reconstruction**
  - Builds upon SAFIRE with more advanced modeling capabilities aiding in theoretically improved edge detection
Siemens Healthcare

Images courtesy Dr. Stephan Achenbach, Erlangen University. a. FBP, b.
Toshiba Healthcare

• AIDR and AIDR-3D: Adaptive Iterative Dose Reduction:
  • Initially operated in the imaging domain the introduction of AIDR 3D allowed evaluation in the raw data space with photon statistics and scanner specific system modelling employed
  • Recently introduced FIRST: Forward projected model-based Iterative Reconstruction Solution
Images courtesy Dr. Marcus Chen, NIH Bethesda. A,C. FBP, B,D. AIDR-3D
Some Real World Examples

- Lung Nodules
- CT KUB
Lung Nodules and Dose Reduction

The New England Journal of Medicine

Reduced Lung-Cancer Mortality with Low-Dose Computed Tomographic Screening

The National Lung Screening Trial Research Team*

Abstract

Aberle D. et al. NEJM 2011
Lung Nodules: Study ongoing at SPH:

PROVIDENCE HEART + LUNG INSTITUTE AT ST. PAUL’S HOSPITAL
New solutions for health
• 2 readers
• 20 CTs
• 104 unique nodules
A: Regular Dose FBP
B: Regular Dose ASIR
C: Regular Dose MBIR
D: Low Dose FBP
E: Low Dose ASIR
F: Low Dose MBIR

1.2mSv
0.2mSv
Bottom Line

• Regular dose: 1mSv. Low dose: 0.21mSv
• Significant noise reduction with MBIR and ASIR vs FBP (comparing between scans of the same dose)
• For nodules >6mm agreement between regular and low dose was excellent (k=0.79)
CT KUB: Study ongoing at SPH
Examination of Low Dose CT KUB for Renal Volume assessment

The NEW ENGLAND JOURNAL of MEDICINE

ORIGINAL ARTICLE

Tolvaptan in Patients with Autosomal Dominant Polycystic Kidney Disease

Vicente E. Torres, M.D., Ph.D., Arlene B. Chapman, M.D., Olivier Devuyst, M.D., Ph.D., Ron T. Gansevoort, M.D., Ph.D., Jared J. Grantham, M.D., Eiji Higashihara, M.D., Ph.D., Ronald D. Perrone, M.D., Holly B. Krasa, M.S., John Ouyang, Ph.D., and Frank S. Czerwiec, M.D., Ph.D., for the TEMPO 3:4 Trial Investigators*
• 30 subjects with known ADPKD
• 3 scans each: MRI, CT KUB, and low dose CT kidneys
• Hypothesis: low dose CT with IR tools applied will allow accurate renal volume assessment
FBP regular dose: 15.5 mGy (CTDInv)

MBIR low dose 4.1 mGy (CTDInv)

120 kVp, mA 100-130

120 kVp, mA 20-30
MRI via manual tracing

X and Y axis: Volume in mls

Low Dose CT
Bottom Line

- Good correlation with gold standard MRI volumes for all CTs
- Correlation improved between LD FBP and LD MBIR
CARIBBEAN AIRPORT SECURITY
Summary:

• mAs:
  • Use dose modulation.

• kVp:
  • Consider either BMI based kVp choices i.e. 80 kVp for thin patients, and 120+kVp for larger patients

• Scan and phase creep
  • Combined phases, virtual noncontrast?

• Iterative reconstruction
  • Explore the use of IR on your scanner