Integrating Noise Reduction Technology into your Practice to Reduce Patient Dose without Sacrificing Image Quality

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DISCLOSURES

Research Support:
Siemens Healthcare

Off Label Usage
None
Overview

• Noise reduction
  – Context
  – Rationale

• Approaches

• Evidence for improvement of image quality and observer performance

• Clinical implementation
  – Practical approaches
  – For image quality improvement
  – For dose reduction
The “Good” Exam

• Justified

Benefit

• Optimized

- Use doses that are as low as reasonably achievable (ALARA) without compromising diagnostic task.
- Adapts CT acquisition to patient and disease

McCollough et al. AJR 2009
CT Dose Summit 2011

**Typical Maximum Organ Doses (mGy)**

- **Radiographic**
  - Chest
  - C-Spine
  - Skull
  - Upper GI
  - Mammogram

- **CT**
  - Chest
  - Abdomen
  - Pelvis
  - Head

**Chance of an effect**

- Predictable effects
  - Skin effects
    - Cataracts
    - Temporary hair loss
  - Solid tumor cancer treatment

$x \times 1000$

**Courtesy Dr. Cynthia McCollough**
Radiation Risk

Leukemias excluding CLL

Solid Neoplasms

* 174,541 British Radiation Safety Workers
From Muirhead et al. Br J CA 2009
Radiation Risk

Excess Deaths Per 100 Expected

Natural Background

Linear No-Threshold Risk Model

BEIR VII

• “At doses of 100 mSv or less, statistical limitations make it difficult to evaluate cancer risk in humans.”

• “The preponderance of information indicates that there will be some risk, even at low doses, although the risk is small.”

- U. S. National Academies of Science
Dealing with Small Potential Risks

- Justification largely driven by benefit
Dose Is Not Driving Justification
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Huprich et al.  Radiology 2011
Dose Is Not Driving Justification
Dealing with Small Potential Risks

• Justification largely driven by benefit

• Benefit of CT cannot be achieved without imaging
Typical Body CT Doses over 2 Decades

![Bar chart showing typical body CT doses over 2 decades.](chart.png)

- 10 mm section width
- 7 - 10 mm
- 1 - 5 mm

Courtesy Dr. Cynthia McCollough
CT Dose Summit 2011

Perception

The New York Times

Report Links Increased Cancer Risk to CT Scans

By THE ASSOCIATED PRESS
Published: October 10, 2009

Millions of people have been exposed to dangerous levels of radiation and are at risk of developing cancer, the Food and Drug Administration warns. In the past decade, the number of CT scans performed in the United States has increased by 260 percent, and US officials are worried that the risk of unnecessary radiation exposure is “weakening” efforts to reduce cancer.

Cedars-Sinai investigated for significant radiation overdoses of 206 patients

The finding prompts the FDA to issue an alert urging protocols for CT scans.

Class Action Lawsuit Filed Against Cedars-Sinai Over CT Radiation Overdose

October 10, 2009 | Alan Zarembo

More than 200 patients at Cedars-Sinai

CT Scan Increase Could Mean More Cancer Down the Road

U.S. probing more cases of CT radiation overexposure

WASHINGTON (Reuters) - U.S. regulators are probing more cases of patients who received too much radiation in CT scans.

Doctors 'Shocked' by Radiation Overexposure at Cedars-Sinai

Medical Scans Continue Increasing Our Exposure to Radiation, Experts Say

CT scan radiation can equal nuclear bomb exposure

New Scientist.com

12:03 11 May 2007

Overzealous doctors who order unnecessary body scans use X-ray technology are placing their patients at risk of cancer, radiologists warn.

Radiation from such scans is in some cases equivalent to that received by some survivors of the Hiroshima and Nagasaki atomic bombs, they say. In response, hospitals and professional associations, such as the American College of Radiology, are taking new steps to promote more careful use of scanning technologies.

Study: CT scans raise cancer risk

updated 7:45 a.m. EST, Wed November 28, 2007

Study: Increased Use of CT Scan Poses Cancer Risk

Thursday, November 29, 2007

Associated Press
Rationale for Dose Reduction

• Lower doses can be used in numerous clinical situations to accomplish the diagnostic task

• With noise reduction, overall dose for many CT exams will be similar or less than annual background radiation
  – LARGE POTENTIAL to overcome patient/physician reticence to undergo beneficial and justified CT imaging
  – Especially important for screening, repeat exams, young patients
Noise Reduction

The purpose of noise reduction is to “increase fidelity to a higher dose image.” - Amy Hara, MD
Noise Reduction

**Full dose** – 120 kV & 240 Qual Ref mAs

**Half dose** – 120 kV & 120 Qual Ref mAs + Noise Reduction
Differences in Image-based Noise Filters

- SharpView Careful Noise Reduction
- SharpView Subtraction
- Mayo Image-based Noise Filter
- Mayo Image-based Noise Filter

CT Dose Summit 2011
Differences in Method and Implementation

- **Acquisition**
  - Projection Data
  - Projection-space Filters

- **Image Reconstruction**
  - Filtered Back Projection
  - Reconstruction kernel
  - Iterative Reconstruction (e.g., MBIR)

- **CT image**
  - Filtered CT image

- **Image-space Noise Reduction**
  - (e.g., SharpView)

**Iterative Noise Reduction Methods**
- (e.g., ASIR, SAFIRE)
Noise Reduction Myths

• Noise reduction reduces radiation dose
  – “ASIR-enabled”, “SAFIRE-enabled”

• Noise reduction improves lesion detection

• It’s “iterative reconstruction”
Noise Reduction Myths

Noise Reduction Reduces Dose

- Only kV and mAs reduction reduces dose
- Noise floor and cross-scatter reduction would likely help
- Radiologists are really good at looking at low-dose images without noise reduction**
  - Crohn’s, diverticulitis, appendicitis, renal stone detection
  - Observer performance is preserved

** Allen et al. AJR 2010; Kambadakone et al. AJR 2010; Seo et al. AJR 2009
Noise Reduction Myths

Noise Reduction Improves Detection

- Multiple studies have shown noise reduction does improve image quality
- However, low dose images without noise reduction show the same CT findings
Is Noise Reduction Improving Diagnosis?
**Myths: Denoising Improves Detection**

Singh (2010). Abdominal CT: Comparison of Techniques

- 22 pts
- 4 additional scans @ 50 – 200 mAs, reconstructed with FBP & 30 – 70 % ASIR
- Significant improvement in noise, IQ, conspicuity at lowest dose level
- No loss of contrast or sharpness
- No lesions missed on FBP or ASIR images

Myths: Denoising Improves Detection

- 92 pts
- FD, ½ dose, ½ dose with noise reduction
- ½ dose = 3.5 mGy CTDIvol
- Evaluated imaging findings of inflammation at TI
- 1/2 dose with and without noise reduction found agreement with full dose in > 85% of cases
Myths: It’s “Iterative Reconstruction”

• Explanation of MBIR or “true” IR
• Other “iterative” noise reduction methods that sample projection space
• Other “iterative” noise reduction in image space
• Observer comparisons not done
• Differences may be idiosyncratic (to practices) and practical
Iterative Reconstruction

- IR has an advantage in accurately modeling the system geometry, incorporating physical effects like beam spectrum, noise, beam hardening effect, scatter and incomplete data sampling.
- Different degrees of credibility among projection data
- More accurate noise models
  - photon statistics
  - other physical properties of the data acquisition
- May improve spatial resolution and reduce image artifacts such as beam hardening, windmill, and metal artifacts
- High computation load
Iterative reconstruction

- Projection Data
- Compare & update
- Modified Data
- Iteration loop: Optimize an objective function
  - Projection (System model)
- Simulated Projection data
- Image
- Final Image
- Backprojection
Ultra low dose with MBIR

**MBIR** = Model based iterative reconstruction

Example: CT at 10 mAs (routine = 200 mAs)

64 x 0.625, helical pitch 1, 120kVp

*Same pt, same scan*

(MBIR, GE Healthcare)  Courtesy Dr. Amy Hara
Artifact Improvement with Iterative Sampling of Projection Data

Subtle D2 Neo-terminal ileum and Perianal Fistula can be seen on half-dose ± SAFIRE (2 mm slice thickness, corresponding to 3.3 mGy), even though IQ markedly improved.
Differences in Method and Implementation

Acquisition → Projection Data → Image Reconstruction

- Filtered Back Projection
- Reconstruction kernel
- Iterative Reconstruction (e.g., MBIR)

Projection-space Filters

Iterative Noise Reduction Methods (e.g., ASIR, SAFIRE)

CT image → Filtered CT image

Image-space Noise Reduction (e.g., SharpView)
Several Noise Reduction Strategies

- Reconstruction kernel
- Image-space denoising
- Iterative reconstruction
- Iterative noise reduction methods sampling projection space

61% noise reduction (3D ORA kernel)
Comparison of Noise Reduction Methods

IRIS I40

SharpView A81

Original B40

Projection Space 1

SAFIRE

Projection Space 2
Integration of Noise Reduction on a Departmental Basis: Practical Considerations

PACS

Noise Reduction Within Image Reconstruction System
Integration of Noise Reduction on a Departmental Basis: Practical Considerations
Steps for Implementation

• Start with exams where image quality improvement will help
  – e.g., small bowel masses, HCC, pancreatic mass
Image-based Denoising
Image Quality Improvement
Image-based Denoising
Image Quality Improvement

August 5, 2011

September 30, 2011
Steps for Implementation

- Start with exams where image quality improvement will help
  - e.g., small bowel masses, HCC
- Satisfy yourself that you will not lose small low contrast objects
  - Try your noise reduction out on thinner slices with subtle lesions
What about low contrast detectability?

2 mm B40

1 mm B40

15 HU △
What about low contrast detectability?

2 mm B40

1 mm B40

1 mm Slices with SAFIRE

I40_1
I40_2
I40_3
I40_4
I40_5
What about low contrast detectability?

20 HU Δ lesion  
5 mm => 3 mm

3 mm Slices with SAFIRE
Steps for Implementation

• Start with exams where image quality improvement will help
  – e.g., small bowel masses, HCC

• Satisfy yourself that you will not lose small low contrast objects
  – Try your noise reduction out on thinner slices with subtle lesions

• Focus on targeted exams
  – Reduce dose using AEC settings and implement noise reduction
  – Increase dose reduction as you feel more comfortable
Steps for Implementation

• Targeted exams
  – Younger patients (e.g., CT enterography)
  – Screening, f/u exams (e.g., CT colonography, CTU)
  – Routine abdomen pelvis

• Establish how to image at lower dose level that does not diminish observer performance
  – In your own practice
  – In the literature
  – Use your AEC to accomplish (usually 30 – 40%) dose reduction

• Compare image quality to pts with prior exams
Implementing Noise Reduction

  - Lowered dose by using AEC (noise index: 22 → 31) followed by recon using 40% ASIR
  - 53 pts with prior CT exams
  - Overall 33% reduction in dose (25 → 17 mGy CTDIvol)
  - Compared image quality to prior exams at routine dose
  - Lower-dose ASIR: ↓noise, ↓sharpness, = diagnostic acceptability
Iterative Noise Reduction
Impact on Implementation & Image Quality

Implementing Noise Reduction
Routine Abdomen Pelvis with Contrast

- Lower AEC settings by 1/3
- Care kV (120 kV, 240 → 180 Qual.
- Apply noise reduction
- Non-cancer & cancer follow-up

CTDIvol = 10.2 mGy
CTDIvol = 5.7 mGy
2 weeks apart
Implementing Noise Reduction

Routine Abdomen Pelvis with Contrast

- Lower AEC settings by 1/3
- Care kV (120 kV, 240 → 180 Qual. ref. mAs)
- Apply noise reduction
- Non-cancer & cancer follow-up

CTDIvol = 12.4 mGy

CTDIvol = 5.9 mGy
Implementing Noise Reduction

Biphase Liver with Contrast

- Lower AEC settings by 1/3
- Care kV (120 kV, 350 → 180 Qual. ref. mAs)
- Apply noise reduction
- Follow-up

CTDIvol = 24.0 mGy

CTDIvol = 16.8 mGy
Implementing Noise Reduction

Fliceck et al. AJR 2010
- Phantom & human study (18 pts)
- 50 mAs supine vs. 25 mAs prone + ASIR
- Lower dose ASIR acquisition – no difference in 2D or 3D IQ

Reducing the Radiation Dose for CT Colonography Using Adaptive Statistical Iterative Reconstruction: A Pilot Study

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OBJECTIVE. The purpose of our study was to evaluate the feasibility of preserving image quality during CT colonography (CTC) using a reduced radiation dose with adaptive statistical iterative reconstruction (ASIR).

MATERIALS AND METHODS. A proven colon phantom was imaged at standard dose settings (50 mAs) and at reduced doses (10–40 mAs) using six different ASIR levels (0–100%). We assessed 2D and 3D image quality and noise to determine the optimal dose and ASIR setting. Eighteen patients were then scanned with a standard CTC dose (50 mAs) in the supine position and at a reduced dose of 25 mAs with 40% ASIR in the prone position. Three radiologists blinded to the scanning techniques assessed 2D and 3D image quality and noise at three different colon locations. A score difference of ≥ 1 was considered clinically important. Actual noise measures were compared between the standard-dose and low-dose acquisitions.

RESULTS. The phantom study showed image noise reduction that correlated with a higher percentage of ASIR. In patients, no significant image quality differences were identified between standard- and low-dose images using 40% ASIR. Overall image quality was reduced for both image sets as body mass index increased. Measured image noise was less with the low-dose technique using ASIR.
Implementing Noise Reduction

Practice Change
- Routine dose supine
- $\frac{1}{2}$ dose additional positions with noise reduction
Important Reasons to Consider Noise Reduction

Image quality, confidence, fatigue & acceptability

19 yo female
CTDI vol 3.5 mGy

2mm slice
B40

2mm slice
SAFIRE
Conclusions

• Noise reduction can significantly improve image quality
  – Improves conspicuity of subtle lesions
  – Facilitates substantial and routine dose reduction without sacrificing image quality
  – Dose reduction comes from lowering mAs settings appropriately

• Observer performance data lacking

• Should be utilized differently depending on diagnostic task

• Multiple approaches have different practical implications