Ultralow Dose Chest CT

with MBIR

Ella A. Kazerooni, M.D.
Professor & Director
Cardiothoracic Radiology
Associate Chair for Clinical Affairs
University of Michigan
Consultant: GE Healthcare
Low dose vs ultra low dose chest CT

2-3 mSv
LDCT FBP

0.2 mSv
ultraLDCT : MBIR
Advanced modeling of system statistics & optics to:

- reduce noise
- increase spatial resolution
- increase contrast resolution
- at the same (or lower) radiation doses

MBIR (Veo) approved by US FDA September 2011
NIH funded collaboration: PI Jeff Fessler PhD UM School of Engineering, GE Global Research and U of M Radiology Mitch Goodsitt PhD CT physicist & Ella Kazerooni MD Thoracic Radiology
MBIR reconstruction review

Penalized weighted least-squares (PWLS) cost function:

$$\hat{x} = \arg \min_x \Psi(x), \quad \Psi(x) = \frac{1}{2} \|y - Ax\|_W^2 + \beta R(x)$$

- $y$: sinogram data, fully precorrected including logarithm
- $A$: system matrix (forward projector)
- $W = \text{diag}\{w_i\}$: diagonal data-dependent statistical weighting matrix; ideally should account for all precorrection steps and both photon and electronic noise.
- $\beta$: regularization parameter, controls resolution/noise trade-off
- $R(x)$: regularizer, often has the form $R(x) = \sum_k \psi([Cx]_k)$ for some potential function $\psi$
- The “arg min” part requires an iterative optimization algorithm.
- Principles generalize to penalized-likelihood
• Lung is a great target for low dose CT efforts
• Inherent contrast between lung (air) and tissue (vessels & airways)
• Tissues extracted as arborizing structures
• Lung segmentation straightforward
• At or near CXR exposure CT exams
• Trade off may be quantitative analysis
  ▪ lowest exposure vs. most accurate measurement
National Lung Cancer Screening Trial

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

The National Lung Screening Trial Research Team*

20% lung cancer mortality reduction

6.9% all cause mortality reduction

screen 320 individuals to save 1 from lung cancer death
Lung Cancer CT Screening Limitations

- **false positives:**
  - NLST: 40% of subjects had ≥ 1 FP over 3 years
  - Mayo: 75% of subjects had ≥ 1 FP over 5 years

- **radiation concerns:**
  - from screening LDCT exams
  - serial CT used as the primary tool to further evaluate small nodules, PET/CT, etc

indeterminate lung nodules
• assumptions:
  • entire US population current/former smokers
  • age 50-75 years
  • annual CT until age 75 (5.2 ± 0.9 mGy to lung; 60 mAs)
  • 50% compliance rate
  • atomic bomb survivor cohort for predicting risk

• expect 1.9 million lung cancers
• 36,000 additional lung cancers attributed to CT
• 1.8% increase in lung cancer (95% CI 0.5-5.5%)
<table>
<thead>
<tr>
<th>Parameter</th>
<th>GE-VCT(64) 64 slice</th>
<th>Siemens Sensation 64</th>
<th>Phillips MX8000 16 slice</th>
<th>Toshiba Aquillon 16 slice</th>
</tr>
</thead>
<tbody>
<tr>
<td>KV</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Gantry Rotation Time</td>
<td>0.5 sec</td>
<td>0.5 sec</td>
<td>0.5 sec</td>
<td>0.5 sec</td>
</tr>
<tr>
<td>mA (Regular-Large Patient)</td>
<td>50-100</td>
<td>50-100</td>
<td>75-15-</td>
<td>80-160</td>
</tr>
<tr>
<td>mAs (Regular-Large)</td>
<td>25-50</td>
<td>25-50</td>
<td>37.5-75</td>
<td>40-80</td>
</tr>
<tr>
<td>Scanner Effective mAs (Reg-Large)</td>
<td>27-53</td>
<td>25-50</td>
<td>25-50</td>
<td>26.7-53.3</td>
</tr>
<tr>
<td>Detector Collimation (mm): T</td>
<td>0.625 mm</td>
<td>0.6 mm</td>
<td>.75 mm</td>
<td>2 mm</td>
</tr>
<tr>
<td>Number of Active Channels: N</td>
<td>64</td>
<td>32</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Detector configuration: N x T</td>
<td>64 x 0.625 mm</td>
<td>32 x 0.6 mm</td>
<td>16 x 0.75</td>
<td>16 x 2</td>
</tr>
<tr>
<td>MODE (Thick-Speed) or Console Collimation</td>
<td>.625/984/39.37</td>
<td>64 x 0.6 mm</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Table Incrementation (mm/rotation): I</td>
<td>39.37 mm</td>
<td>19.2 mm</td>
<td>18 mm</td>
<td>48 mm</td>
</tr>
<tr>
<td>Pitch ([mm/rotation]/configuration): I/NT</td>
<td>0.984</td>
<td>1.0</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Table speed (mm/second)</td>
<td>78.74 mm/sec</td>
<td>38.4 mm/sec</td>
<td>36 mm/sec</td>
<td>96 mm/sec</td>
</tr>
<tr>
<td>Scan time (40 cm thorax)</td>
<td>5.1 sec</td>
<td>11 sec</td>
<td>11 sec</td>
<td>4.2 sec</td>
</tr>
<tr>
<td>Max Nominal Reconstructed Slice Width</td>
<td>2.5 mm</td>
<td>2 mm</td>
<td>2 mm</td>
<td>2 mm</td>
</tr>
<tr>
<td>Reconstruction Interval</td>
<td>2.0 mm</td>
<td>1.8 mm</td>
<td>1.8 mm</td>
<td>1.8 mm</td>
</tr>
<tr>
<td>Reconstruction Algorithm</td>
<td>STD</td>
<td>B30f</td>
<td>B or C</td>
<td>FC 10</td>
</tr>
<tr>
<td># Images/Data set (40 cm Thorax)</td>
<td>200</td>
<td>223</td>
<td>223</td>
<td>223</td>
</tr>
<tr>
<td>CTDIvol Dose in mGy (Regular-Large)</td>
<td>2.2-2.4 mGy</td>
<td>1.9-3.8 mGy</td>
<td>1.9-3.8 mGy</td>
<td>2.7-5.4 mGy</td>
</tr>
</tbody>
</table>
Lung Nodule CT Tasks

- Detection
- Characterization
  - Qualitative
    - Descriptive: ground glass, solid etc
  - Semi-quantitative
    - Caliper sizing
  - Quantitative
    - Volumetric measurement
- Follow up
Model-Based Iterative Reconstruction Technique for Ultralow-Dose Computed Tomography of the Lung

A Pilot Study

Yoshitake Yamada, MD,* Masahiro Jinzaki, MD, PhD,* Yutaka Tanami, MD, PhD,* Eisuke Shiomi, MD,† Hiroaki Sugiura, MD,* Takayuki Abe, PhD,‡ and Sachio Kuribayashi, MD, PhD*

DOI 10.1007/s00330-012-2452-z

Model-based iterative reconstruction technique for radiation dose reduction in chest CT: comparison with the adaptive statistical iterative reconstruction technique

Masaki Katsura • Izuru Matsuda • Masaaki Akahane • Jiro Sato • Hiroyuki Akai • Koichiro Yasaka • Akira Kunimatsu • Kuni Ohtomo
MBIR Lung CT for Nodules
Yamada et al. Invest Radiol 2012;8:482-489
Keio University School of Medicine, Tokyo

- 52 subjects dual chest CT acquisitions March-May 2011
  - LDCT 50 mAs “screening” eff dose 2.1 mGy
  - uLDCT 4 mAs eff dose 0.17 mGy

- Reconstructions
  - LDCT – filtered back projection LDCT – FBP
  - uLDCT – filtered back projection uLDCT – FBP
  - uLDCT – MBIR uLDCT – MBIR

- 2 blinded readers

- Compared noise, subjective image quality & lung nodule detection on 1.25 mm axial images
“blotchy pixelated appearance” on all uLDCT-MBIRs

<table>
<thead>
<tr>
<th>Blotchy pixelated appearance</th>
<th>LDCT-FBP</th>
<th>ULDCT-MBIR</th>
<th>ULDCT-FBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>1.00 ± 0.00</td>
<td>2.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>Right upper lobe</td>
<td>1.00 ± 0.00</td>
<td>2.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>Right middle lobe</td>
<td>1.00 ± 0.00</td>
<td>2.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>Right lower lobe</td>
<td>1.00 ± 0.00</td>
<td>2.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>Left upper lobe</td>
<td>1.00 ± 0.00</td>
<td>2.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>Lingula</td>
<td>1.00 ± 0.00</td>
<td>2.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>Left lower lobe</td>
<td>1.00 ± 0.00</td>
<td>2.00 ± 0.00</td>
<td>1.00 ± 0.00</td>
</tr>
</tbody>
</table>

1 = none; 2 = present **not** impacting screening results
3 = impacting screening results
“blotchy pixelated appearance”
“blotchy pixelated appearance”
MBIR Lung CT for Nodules

Yamada et al. Invest Radiol 2012;8:482-489
Keio University School of Medicine, Tokyo

Subjective image noise
- $uLDC T - MBIR = LDCT - FBP$
- $uLDC T - MBIR < uLDC T - FBP (p < 0.001)$
MBIR Lung CT for Nodules
Yamada et al. Invest Radiol 2012;8:482-489
Keio University School of Medicine, Tokyo

- **Artifacts**
  - $uLDCT - FBP > uLDCT - MBIR > LDCT - FBP \ p < 0.001$

- **Image sharpness**
  - $uLDCT - MBIR \& uLDCT - FBP$ equivalent
  - $LDCT - FBP$ significantly more sharp ($p < 0.001$)
Artifacts with MBIR
Nodule detection - LDCT-FBP used as “truth”

Calcified nodules (n = 26, 2-10 mm diameter)
  uLDCT – MBIR & uLDCT – FBP detected all nodules

Non calcified nodules (n = 184, 1-30 mm, mean 4 ± 3)
  uLDCT – MBIR > uLDCT – FBP (p < 0.002)
  TPF all 0.905 0.804
  TPF ≥ 4 mm 0.944 0.833
  TPF < 4 mm 0.884 0.789
  FPR all* 0.125 0.202

* Upon review of misses reviewed – due to noise and artifacts
The patients...

- Age 38 - 84 years (mean 66.3)
- Weight
  - range: 37 - 84 kg (82 - 185 lbs)
  - mean: 55.9 ± 11.9 kg (123 ± 26 lbs)
- BMI*
  - range: 15.4 - 30.7
  - mean: 21.7 ± 3.5

*healthy weight 18.5-25; overweight 25-30; moderately obese 30-35
MBIR Lung CT for Nodules

Matsura et al. Eur Rad 2012;8:1613-1623
University of Tokyo

- **100 subjects dual chest CT acquisitions July 2011**
  - LDCT
    - *eff dose 4.04 mGy*
  - uLDCT
    - *eff dose 0.55 mGy*

- **Reconstructions**
  - LDCT – filtered back projection with ASIR
  - uLDCT – filtered back projection ASIR
  - uLDCT – MBIR

- **2 blinded readers**

- Compared noise, subjective image quality & lung nodule detection on 0.625 mm axial images
Table 4. Objective image quality (mean CT value and image noise) measured within each region of interest.

<table>
<thead>
<tr>
<th>Region of interest</th>
<th>Reference-dose ASIR</th>
<th>Low-dose ASIR</th>
<th>Low-dose MBIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lung parenchyma (CT value)</td>
<td>-891.73±27.66</td>
<td>-889.78±28.68</td>
<td>-889.18±28.25</td>
</tr>
<tr>
<td>Lung parenchyma (image noise)</td>
<td>24.93±4.65*</td>
<td>49.24±9.11*</td>
<td>16.93±3.00*</td>
</tr>
<tr>
<td>Descending aorta (CT value)</td>
<td>38.05±5.21</td>
<td>37.26±7.28</td>
<td>36.86±5.76</td>
</tr>
<tr>
<td>Descending aorta (image noise)</td>
<td>10.01±1.35†</td>
<td>23.42±3.83†</td>
<td>12.76±1.25†</td>
</tr>
</tbody>
</table>
### Table 5: Subjective image quality scores for the two radiologists (reader 1 and reader 2)

<table>
<thead>
<tr>
<th>Image quality</th>
<th>Reader 1</th>
<th>LDCT-ASIR</th>
<th>uLDCT-ASIR</th>
<th>uLDCT-MBIR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reference-dose</td>
<td>Low-dose</td>
<td>Low-dose</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASIR</td>
<td>ASIR</td>
<td>MBIR</td>
<td></td>
</tr>
<tr>
<td>Noise (1/2/3/4/5)</td>
<td>0/0/99/1/0*</td>
<td>0/1/5/59/5*</td>
<td>0/100/0/0*</td>
<td></td>
</tr>
<tr>
<td>Motion artefact (1/2/3)</td>
<td>96/4/0††</td>
<td>95/5/0††</td>
<td>77/23/0††</td>
<td></td>
</tr>
<tr>
<td>Streak artefact (1/2/3)</td>
<td>99/1/0†</td>
<td>6/12/82†</td>
<td>98/2/0†</td>
<td></td>
</tr>
<tr>
<td>Pixellated blotchy appearance (1/2/3)</td>
<td>100/0/0††</td>
<td>99/1/0††</td>
<td>1/99/0††</td>
<td></td>
</tr>
<tr>
<td>Diagnostic acceptability (1/2/3/4)</td>
<td>99/1/0/0††</td>
<td>6/10/49/35††</td>
<td>94/6/0/0††</td>
<td></td>
</tr>
</tbody>
</table>
MBIR Lung CT for Nodules
Matsura et al. Eur Rad 2012;8:1613-1623
University of Tokyo

Nodule detection not studied
The patients...

- Age mean 65.6 ± 12.4 years
- Weight
  - range: not reported
  - mean: 58 ± 13 kg (128 ± 29 lbs)
    1 std dev 99-157 lbs (approx 68% of subjects)
    2 std dev 70-186 lbs (approx 95% of subjects)
- BMI not reported
MBIR Lung CT for Nodules
Neroladaki et al. Eur Radiol 2012
Geneva University Hospital

- **42 subjects**
  - SDCT or LDCT (11.2 or 2.7 mSV)
  - uLDCT (0.16 mSv) (*in the range of 2view CXR*)

- **Reconstructions**
  - SDCT or LDCT – filtered back projection
  - uLDCT – filtered back projection
  - uLDCT – ASIR
  - uLDCT – MBIR

- uLDCT– MBIR better image quality than uLDCT ASIR or FBP; quality inferior for ground glass and emphysema

- BMI mean 25.8 males, 27.8 females; “overweight”
LDCT with ASIR

LDCT with MBIR

255 lbs, BMI 34
uLDCT with ASIR

255 lbs, BMI 34

uLDCT with MBIR
LDCT – FBP with ASIR

LDCT with MBIR

255 lbs, BMI 34
ultraLDCT

uLDCT – FBP with ASIR
uLDCT with MBIR

255 lbs, BMI 34
LDCT vs uLDCT

LDCT ASIR
LDCT MBIR
uLDCT ASIR
uLDCT MBIR
LDCT vs uLDCT

LDCT ASIR

LDCT MBIR

uLDCT ASIR

uLDCT MBIR

255 lbs
BMI 34
LDCT vs uLDCT - GGO

BMI 36.6

200 lbs

LDCT ASIR
LDCT MBIR
uLDCT ASIR
uLDCT MBIR
Impact of MBIR on Nodule Volume? TBD

- Low dose CT (conventional low dose) underestimates small nodule volume compared to standard dose chest CT (de Jong et al; 2012 Oct AJR)
  - LDCT vs contrast enhanced standard chest CT
  - CTDIvol 2.2 vs 5.5-20 mGy
  - 200 mm$^3$ threshold or approx 8 mm below which nodules were undersized by approx 14-16%
**MBIR Lung CT for Nodules**

- Substantial radiation exposure reduction
- Reduces noise back to standard low dose CT levels
- Blotchy pixelated appearance does not appear to subjectively impact diagnostic quality of chest CTs
- Not validated in US patient population size cohort
- More work on diagnostic accuracy and impact on nodule quantification is needed
Ultralow Dose Chest CT
with MBIR

Ella A. Kazerooni, M.D.
Professor & Director
Cardiothoracic Radiology
Associate Chair for Clinical Affairs
University of Michigan