Adaptive Imaging: Review of techniques and update on state-of-the-art CT

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TPS consultant GE Healthcare, supplies CT protocols under a licensing agreement to GE Healthcare, founder Protocolshare.org LLC, CAB and consultant to iMALOGIX, consultant Takeda Pharmaceuticals
1. Motivation for Patient Specific Imaging in CT: Cardiac
2. Heart Rate based Adaption
3. Motivation for Patient Specific Imaging in CT: Fluence modulation
4. Patient Specific Fluence Modulation
• Human body
  – It is not static
    • Blood is always moving through arteries/veins and perfusing through soft tissue
    • Heart is always moving
    • Lungs are always moving
Motivation for patient specific imaging in CT

- Human body
  - It is not static
  - Blood is always moving through arteries/veins and perfusing through soft tissue
    - Rate of blood movement is a function of cardiac output, local impedance (i.e. is there a plaque?)
    - Opacification level is a function of blood pool volume
Enhancement seen inside vessels usually much higher than inside parenchyma.

Brain tissue (gray/white)

artery

vein
• **Human body**
  - It is not static
  - Heart is always moving

This may not seem fast, but consider we commonly use a RFOV of 25 cm and 512 voxels, that’s a voxel size of 0.48 mm. In 1 second @ 70 mm/s...we will see blurring
Human body
- It is not static
- Heart is always moving

Motion varies a lot w.r.t phase/cycle
Motion varies a lot by location within/on the heart
• Human body
  - It is not static
    • Lungs are always moving...even during breath holds!

AAPM Report 91 “The management of respiratory motion in Radiation Oncology”

“Computed Tomography” by Hsieh
AAPM Report 91 “The management of respiratory motion in Radiation Oncology”

### Table 2. Lung tumor-motion data. The mean range of motion and the (minimum–maximum) ranges in millimeters for each cohort of subjects. The motion is in three dimensions (SI, AP, LR).

<table>
<thead>
<tr>
<th>Observer</th>
<th>SI</th>
<th>AP</th>
<th>LR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burns et al.</td>
<td>18.5 (9–32)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Middle, upper lobe</td>
<td>7.5 (2–11)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Chen et al.</td>
<td>(0–50)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Ekberg et al.</td>
<td>3.9 (0–12)</td>
<td>2.4 (0–5)</td>
<td>2.4 (0–5)</td>
</tr>
<tr>
<td>Engelsman et al.</td>
<td>(2–6)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Middle-upper lobe</td>
<td>--</td>
<td>1 (0–5)</td>
<td>1 (0–3)</td>
</tr>
<tr>
<td>Lower lobe</td>
<td>--</td>
<td>0</td>
<td>9 (0–16)</td>
</tr>
<tr>
<td>Erridge et al.</td>
<td>12.5 (6–34)</td>
<td>9.4 (5–22)</td>
<td>7.3 (3–12)</td>
</tr>
<tr>
<td>Ross et al.</td>
<td>--</td>
<td>1 (0–5)</td>
<td>1 (0–3)</td>
</tr>
<tr>
<td>Middle lobe</td>
<td>--</td>
<td>0</td>
<td>9 (0–16)</td>
</tr>
<tr>
<td>Lower lobe</td>
<td>--</td>
<td>1 (0–4)</td>
<td>10.5 (0–13)</td>
</tr>
<tr>
<td>Grills et al.</td>
<td>(2–30)</td>
<td>(0–10)</td>
<td>(0–6)</td>
</tr>
<tr>
<td>Hanley et al.</td>
<td>12 (1–20)</td>
<td>5 (0–13)</td>
<td>1 (0–1)</td>
</tr>
<tr>
<td>Murphy et al.</td>
<td>7 (2–15)</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Platithow et al.</td>
<td>9.5 (4.5–16.4)</td>
<td>6.1 (2.5–9.8)</td>
<td>6.0 (2.9–9.8)</td>
</tr>
<tr>
<td>Middle lobe</td>
<td>7.2 (4.3–10.2)</td>
<td>4.3 (1.9–7.5)</td>
<td>4.3 (1.5–7.1)</td>
</tr>
<tr>
<td>Upper lobe</td>
<td>4.3 (2.6–7.1)</td>
<td>2.8 (1.2–5.1)</td>
<td>3.4 (1.3–5.3)</td>
</tr>
<tr>
<td>Spenoorwoole et al.</td>
<td>5.8 (0–25)</td>
<td>2.5 (0–8)</td>
<td>1.5 (0–3)</td>
</tr>
<tr>
<td>Shimizu et al.</td>
<td>--</td>
<td>6.4 (2–24)</td>
<td>--</td>
</tr>
<tr>
<td>Sökel et al.</td>
<td>(0–13)</td>
<td>(0–5)</td>
<td>(0–4)</td>
</tr>
<tr>
<td>Stevens et al.</td>
<td>4.5 (0–22)</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>


### Table 3. Abdominal motion data. The mean range of motion and the (minimum–maximum) ranges in millimeters for each site and each cohort of subjects. The motion is in the superior–inferior (SI) direction.

<table>
<thead>
<tr>
<th>Site</th>
<th>Observer</th>
<th>Breathing mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Shallow</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Surano et al.</td>
<td>20 (10–30)</td>
</tr>
<tr>
<td></td>
<td>Bryan et al.</td>
<td>20 (0–35)</td>
</tr>
<tr>
<td>Liver</td>
<td>Weiss et al.</td>
<td>13 +/- 5</td>
</tr>
<tr>
<td></td>
<td>Haraux et al.</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Surano et al.</td>
<td>25 (10–40)</td>
</tr>
<tr>
<td></td>
<td>Davies et al.</td>
<td>10 (5–17)</td>
</tr>
<tr>
<td>Kidney</td>
<td>SURANO et al.</td>
<td>19 (10–40)</td>
</tr>
<tr>
<td></td>
<td>Davies et al.</td>
<td>11 (5–16)</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>Wade et al.</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Korin et al.</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Davies et al.</td>
<td>12 (7–28)</td>
</tr>
<tr>
<td></td>
<td>Weiss et al.</td>
<td>13 +/- 5</td>
</tr>
<tr>
<td></td>
<td>Giraud et al.</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Ford et al.</td>
<td>20 (13–31)</td>
</tr>
</tbody>
</table>
Outline

1. Motivation for Patient Specific Imaging in CT: Cardiac
2. Heart Rate based Adaption
3. Motivation for Patient Specific Imaging in CT: Fluence modulation
4. Patient Specific Fluence Modulation
• CCTA clinical reality
  – Patients will present with a wide range of heart rates
    • There exists an optimal time post contraction which varies as function of HR → we define image time using a relative time post R peak or an absolute time post R peak
Heart Rate based Adaption

Motion artifact is highly dependent on phase/cycle location
Heart Rate based Adaption

Optimal image reconstruction intervals for non-invasive coronary angiography with 64-slice CT

Abstract

The study aimed to determine optimal imaging intervals for non-invasive coronary angiography with 64-slice CT. Contrast-enhanced, retrospective ECG-gated imaging was performed on 80 healthy volunteers. Thirteen data sets were analyzed for each reconstructed image interval. Depending on the R-R interval, patients were divided into three groups: HR < 65 bpm (n = 40), HR 65 bpm or more (n = 31), and all patients (n = 80). The graph shows the percentage of patients with acceptable image quality (score 1-3) in all coronary segments for different R-R intervals.
Heart Rate based Adaption

Defining the mid-diastolic imaging period for cardiac CT – lessons from tissue Doppler echocardiography

James M Otton, Justin Phan, Michael Fenslay, Ching-yao Yu, Neville Sammel, and Jane McCrohon

Abstract

Background

Aggressive phases. Aimed to image diastole

Methods

We utilize Tissue-Doppler

Low heart rate, best time to image is later in cardiac cycle (yellow line)

High heart rate, best time to image is earlier in cardiac cycle (red line)

CME question answer 😊
Heart Rate based Adaption

- Low Heart Rate: 75%
- Moderate Heart Rate: 70% - 80%
- Intermediate Heart Rate: 40% - 55%
- High Heart Rate: 40% - 55%
• CCTA clinical reality
  – Patients will present with heart rate variability
    • patients with irregular HRs (afib), or with PVCs

Now we need to talk about data collection.
Stable HR has HR variation ~ 5 bpm, variable >5 bpm
Heart Rate based Adaptation

Slow pitch helical/spiral mode
All vendors will just scan faster (i.e. higher pitch) when the heart rate is higher, if irregular beats are detected you would use a lower pitch

“Step and shoot” axial/sequential mode
All vendors will just widen the time the x-rays are on for a given bed position or collect multiple spins one location if an irregular beat is detected

High pitch method “Flash mode”
Accelerate the table to a fast stopped and cover the entire heart in a single beat using a helical/spiral scan mode

Example table of scan pitches as a function of HR

<table>
<thead>
<tr>
<th>Heart rate range</th>
<th>Gantry speed</th>
<th>Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 to 42 BPM</td>
<td>0.4 sec</td>
<td>0.18</td>
</tr>
<tr>
<td>43 to 49 BPM</td>
<td>0.4 sec</td>
<td>0.20</td>
</tr>
<tr>
<td>50 to 59 BPM</td>
<td>0.4 sec</td>
<td>0.23</td>
</tr>
<tr>
<td>60 to 69 BPM</td>
<td>0.4 sec</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Wide axial/sequential mode
Your detector can cover the entire heart, so you sit over the heart with ECG trace on scan when you predict your target phase will be Scan for a longer time when the HR is high or you anticipate an irregular beat

Image from 128-slice Dual Source CT: How Does it Work and What Can it Do? By Bruesewitz et al. Mayo Clinic 2010 RSNA
# Dual Source cCTA Imaging Guidelines

<table>
<thead>
<tr>
<th></th>
<th>Flash / Turbo Flash Mode</th>
<th>Adaptive Cardio Sequence (Prospective Gating)</th>
<th>Retrospective ECG Gating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heart Rate</strong></td>
<td>Flash: &lt;65 bpm, Force: &lt;78 bpm</td>
<td>Any Heart Rate</td>
<td>Any Heart Rate</td>
</tr>
<tr>
<td><strong>HR Stability</strong></td>
<td>Stable</td>
<td>At high HR’s need to be stable</td>
<td>Any Wave Form</td>
</tr>
<tr>
<td><strong>Contrast Amount</strong></td>
<td>Physicians discretion</td>
<td>Scan time x injection rate plus 10 cc’s</td>
<td>Scan time x injection rate plus 10 cc’s</td>
</tr>
<tr>
<td><strong>Injection Rate</strong></td>
<td>5 to 6 ml/s (faster is better)</td>
<td>5 to 6 ml/s (faster is better)</td>
<td>5 to 6 ml/s (faster is better)</td>
</tr>
<tr>
<td><strong>Rotation Time</strong></td>
<td>Flash/Drive: 0.28, Force: 0.25</td>
<td>Flash/Drive: 0.28, Force: 0.25</td>
<td>Flash/Drive: 0.28, Force: 0.25</td>
</tr>
<tr>
<td><strong>CARE kV</strong></td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td><strong>Quality ref mAs</strong></td>
<td>Use Default</td>
<td>Use Default</td>
<td>Use Default</td>
</tr>
<tr>
<td><strong>CARE Dose 4D</strong></td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td><strong>Iterative Reconstruction</strong></td>
<td>ON</td>
<td>ON</td>
<td>ON</td>
</tr>
<tr>
<td><strong>Patient Dose</strong></td>
<td>Less than 1 mSv (100kV)</td>
<td>Depends on ECG pulsing range</td>
<td>Depends on ECG pulsing range, (4% min dose available)</td>
</tr>
<tr>
<td><strong>When to use</strong></td>
<td>Rule out CAD</td>
<td>Routine with HR variability</td>
<td>Atrial Fibrillation, very difficult cases, ECG editing capability</td>
</tr>
<tr>
<td><strong>Cardiac Function</strong></td>
<td>N/A</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Beta Blockers</strong></td>
<td>Physicians discretion</td>
<td>Physicians discretion</td>
<td>Physicians discretion</td>
</tr>
</tbody>
</table>
Limitations of the gated Flash mode:

- The heart rate must be regular. To scan using a high pitch, the table requires about 1 sec to be accelerated. The scanner must accurately predict the timing of future R-waves in order to synchronize the x-ray-on time with the diastolic phase.

Limitations with wide axial scanners and prospective scanning:

- Dose reduction potential is reduced
  - Need to widen gating window
  - Need to “double scan” if a messed up beat is detected
So in summary

- There exist multiple modes for cardiac scanning
- There are optimal modes for different heart rates
- There are optimal modes for different degrees of HR irregularities
- There are different target gating windows for different heart rates
- There are different strategies for dealing with HR irregularities

Current state of the art in cardiac scanning will have the scanner picking the mode and target window for the operator

Honestly, the peer reviewed literature is not the place to understand state of the art in cardiac scanning, get your apps person to send your vendors whitepapers and user manuals for cardiac mode.
Outline

1. Motivation for Patient Specific Imaging in CT: Cardiac
2. Heart Rate based Adaption
3. Motivation for Patient Specific Imaging in CT: Fluence modulation
4. Patient Specific Fluence Modulation
• Human body
  – It varies in size
    • Region to region
    • Angularly
    • Patient to patient
    • As a function of position
Human body
  - It varies in size
    - Region to region
      - head vs. pelvis

Motivation for patient specific imaging in CT

Multiple orders of magnitude changes will occur in detector signal due to body region size changes!
Motivation for patient specific imaging in CT

What we send in

\[ I = I_0 \exp(-\mu x) \]

What we get out

Material property
Motivation for patient specific imaging in CT

- Human body
  - It varies in size
    - Angularly
      - projection through lateral direction longer than AP/PA for all regions except the head
• Human body
  – It varies in size
    • Patient to patient
      ➢ newborn to bariatric adult

**Motivation for patient specific imaging in CT**

6 m.o.  2 y.o.  4 y.o.  
56 y.o.  89 y.o.  79 y.o.

Kids have big heads... that is why they are cute and why we treat them as adults after they turn 7
Motivation for patient specific imaging in CT

Imaging bariatric patients is difficult. Rule of thumb in CT is we need 2x dose for every 4 cm of tissue to maintain image noise. So if we like the scan of a 30 cm person, to get to 50 cm we need 5x dose doublings. If we were using 300 mA for the 30 cm scan, then we need 1,500 mA for the bariatric person!

・Human body
  - It varies in size
    • Patient to patient
      ➢ newborn to bariatric adult

2 months old

Extremely fit 27 year old*

“white out” bariatric patient

10 cm

30 cm

> 53 cm

*its younger me 😊
• Human body
  – It varies in size
    • As a function of position
      ➢ prone versus supine, with respiratory state diaphragm/liver move multiple cm which changes attenuation

Same patient, three different positionings and three different attenuation distributions
Outline

1. Motivation for Patient Specific Imaging in CT: Cardiac
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4. Patient Specific Fluence Modulation
State of the art mA modulation

- Adjustment of tube output as a function of z axis position, or both as a function of z position and gantry angle
- Can reduce dose up to 60% in some cases

Patient Specific Fluence Modulation


Image from Computed Tomography by Willi A. Kalender 2005

mA modulation can handle size and ellipticity changes

Patient Specific Fluence Modulation

- Current state of the art in mA modulation is organ dose modulation
  - Reduces mA when the tube is directly irradiating a radio-sensitive organ
  - Typically, ~30% dose reduction possible

- Patient Specific Fluence Modulation

Old school, no mA modulation

Constant mA

Previous state of the art, angular mA modulation

Lower mA

Higher mA

Current state of the art, organ sparing plus angular and z mA modulation

Reduced mA

Increased mA
• That was mA modulation, what about kV?
Key references for understanding the optimal beam energy in CT

**Application- and patient size-dependent optimization of x-ray spectra for CT**

Willi A. Kalender,²,³ Paul Deak,³ Markus Kellermayer,³ Marcel van Straten,³,⁴ and Sabrina V. Vollmar²

Institute of Medical Physics, University Erlangen-Nürnberg, Henpekte 91 91052 Erlangen, Germany

(Received 21 August 2008; revised 20 November 2008; accepted for publication 6 January 2009; published 25 February 2009)

Although x-ray computed tomography (CT) has been in clinical use for over 3 decades, spectral optimization has not been a topic of great concern; high voltages around 120 kV have been in use since the beginning of CT. It is the purpose of this study to analyze, in a rigorous manner, the energies at which the patient dose necessary to provide a given contrast-to-noise ratio (CNR) for various diagnostic tasks can be minimized. The authors used cylindrical water phantoms and quasihumanomorphic phantoms of the thorax and the abdomen with inserts of 13 mm diameter spherical water-equivalent inserts for simulating the different patient sizes. The authors developed

**Automatic selection of tube potential for radiation dose reduction in CT: A general strategy**

Lifeng Yu,³ Hua Li, Joel G. Fletcher, and Cynthia H. McCollough

Department of Radiology, Mayo Clinic, Rochester, Minnesota 55905

(Received 13 July 2009; revised 23 October 2009; accepted for publication 27 October 2009; published 10 December 2009)

**Purpose:** To optimize radiation dose efficiency in CT while maintaining image quality, it is important to select the optimal tube potential. The selection of optimal tube potential, however, is highly dependent on patient size and diagnostic task. The purpose of this work was to develop a general strategy that allows for automatic tube potential selection for each individual patient and each diagnostic task.

**Methods:** The authors propose a general strategy that allows automatic adaptation of the tube potential as a function of patient size and diagnostic task, using a novel index of image quality, “iodine contrast to noise ratio with a noise constraint (iCNR_NC),” to characterize the different
Optimal Beam Energy Selection in CT

- Raising kV means lower noise for the same dose.
- Lower kV means better image contrast.

Density difference was difference between 10 HU of soft tissue like material.

Iodine difference was difference between iodine rod and background.

Medical Physics, Vol. 36, No. 3, March 2009
Optimal Beam Energy Selection in CT

https://www.edu-quip.co.uk/prod/27573/matrix-springer-3-way-see-saw
<table>
<thead>
<tr>
<th>Canon</th>
<th>GE</th>
<th>Philips</th>
<th>Siemens</th>
</tr>
</thead>
<tbody>
<tr>
<td>mA AEC</td>
<td>SURE Exposure 3D</td>
<td>smartmA</td>
<td>DoseRight</td>
</tr>
<tr>
<td>kV AEC</td>
<td>SURE kV</td>
<td>kV Assist</td>
<td></td>
</tr>
<tr>
<td>Organ sparing</td>
<td>OEM*</td>
<td>ODM</td>
<td></td>
</tr>
<tr>
<td>Quality target</td>
<td>SD</td>
<td>NI</td>
<td>DRI</td>
</tr>
<tr>
<td>Quality target to dose</td>
<td>SD∝ ( \frac{1}{\sqrt{CTDI_{vol}}} )</td>
<td>NI∝ ( \frac{1}{\sqrt{CTDI_{vol}}} )</td>
<td>( CTDI_{vol} \propto (1.12)^{DRI-24} )***</td>
</tr>
<tr>
<td>Quality target to noise</td>
<td>SD≈ Image Noise</td>
<td>NI≈ Image Noise</td>
<td>DRI ( \propto 24 - \frac{\ln(image \ noise)}{2 \ln(1.12)} )***</td>
</tr>
<tr>
<td>Quality Target with patient size</td>
<td>Non linear, not adjustable</td>
<td>constant</td>
<td>Non linear, not adjustable</td>
</tr>
<tr>
<td>Organ Region boost</td>
<td>Allows you to set different SD for different scan regions</td>
<td></td>
<td>Liver Brain DoseRight</td>
</tr>
</tbody>
</table>

*In CT fluoroscopy mode only
**Phillips recommends performing a dual energy scan
*** For dose increase above reference patient DRI
**** For dose decrease below reference patient DRI
Circa ~2012, the concept of fluence modulated imaging in x-ray imaging was not new. Many approaches had been studied and were in clinical use.
In the clinic today, we can write the modulation of the x-ray beam in MDCT as
\[ M(d,n) = F(d)D(n) \]
where \( d \) is the detector element index and \( n \) is the view angle. **THIS IS A SEPARABLE FUNCTION**

The rest of this talk will be about approaches that modulate the fluence profile in real time.
• References for this new type of CT beam fluence modulation
  
  **Stanford group**
  - Working prototype
  - Fluence control models

  **Hokpins group**

  **UW-Madison group**
  - Implemented on a clinical MVCT scanner
  - Prototype

  **Toronto group**
• Bowtie filter works perfectly when
  – Patient object is homogeneous and cylindrical
  – Patient is perfectly centered on isocenter

• Advantages
  – Decrease dose and scatter by ~50%\textsuperscript{1}
  – Increase noise uniformity\textsuperscript{2}

\textsuperscript{1}Graham et al. “Compensators for dose and scatter management in CBCT” Med. Phys. 34 2007
Patient Specific Fluence Modulation

“Computed Tomography Principles, Design, Artifacts, and Recent Advances” by Jiang Hsieh
Patient Specific Fluence Modulation
Patient Specific Fluence Modulation
"Patient Specific Fluence Modulation"

- Side view
- View along fan beam
- Putting a bunch of wedges together
Physics in Medicine & Biology

PAPER

Patient Specific Fluence Modulation

22 March 2016

Fluence-field modulated x-ray CT using multiple aperture devices

Abstract

Tailoring CT scan acquisition parameters to individual patients is a topic of much research in the CT imaging community. It is now common practice to find automatically adjusted tube current options for modern CT scanners. In addition, the use of beam shaping filters, commonly called booster filters, is

PAPER

A prototype piecewise-linear dynamic attenuator

Scott S Hinton, Mark V Peng, Christopher A May, Picha Shurhanschik, Dominik Fleischmorn and
Norbert J Pelc

Published 20 June 2015 • © 2015 Institute of Physics and Engineering in Medicine
Physics in Medicine & Biology: Volume 61, Number 3

Figures • References •

Abstract

The piecewise-linear personalized attenuator has shown promise in simulations for dose reduction in CT.

B

MAD Filter

X-rays

C

MAD1

MAD2

X-rays

D

Transition Fluence Patterns

E

Reducing Fluence Patterns

F

Desired Fluence Patterns

G

Designed Bar Patterns

H

Position on MAD1

I

Position on MAD2

J

Relative Motion

K

MAD Pitch (P)

L

MAD Pitch (P)

M

MAD pitch (P)
Patient Specific Fluence Modulation

No DBA

DBA
• Hopkins group- noise uniformity better with FFMCT relative to static bowtie

Can help us avoid situations like this, bad positioning caused large noise non uniformity
“full” dose

No DBA

“full” dose

DBA

2 times higher dose

No DBA

“full” dose

No DBA

3.6 times higher dose

DBA
Stanford group (Hsieh and Pelc) have looked at how FFMCT can help with photon counting CT via reducing dynamic range needs of detector.
- What about for VOI imaging?
  - Need to predefine a SNR “prescription” for the image
  - Then the required wedge positions must be calculated
- Our first implementation
  - Max signal (minimum wedge thickness) to where ROI intersects wedgelet, minimum signal (maximum wedge thickness) otherwise

\[ p = -\ln \frac{I}{I_o} \]
Clinicians often do not need good image quality everywhere!
Use FFMCT to provide region specific SNR enhancement/suppression

FFMCT implemented on a clinical MVCT scanner

Tomotherapy scanners already have a set of beam modulators, so we used them to do FFMCT!

Scan focused on “VOI 4” is shown here
Toronto group looked at VOI imaging using different types of fluence modulation devices.
• FFMCT can be thought of as a way to actually weight data during the collection process, in stead of post acquisition during reconstruction like one can do with noise weighting schemes in an iterative/non-linear reconstruction algorithm (D term below weights data based on its signal strength)
  – FFMCT would allow one to increase signal levels for highly attenuating rays OR
  – FFMCT would allow one to give up on highly attenuating rays and give them little to no dose

\[ \hat{\mu} = \arg \min_{\mu} \left\{ \frac{1}{2} (p - A\mu)^T D (p - A\mu) + G(\mu) \right\} \]
Thanks!

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Patient Specific Fluence Modulation


