CT Perfusion: How to do it right

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CT Perfusion has a role to play in top 3!

US Causes of Mortality, 2005 (CDC)

- Heart Disease
- Cancer
- Stroke
- Respiratory
- Accidents
- Diabetes
- Alzheimer’s disease
- Influenza/Pneumonia
- Renal
- Septicemia

0 175000 350000 525000 700000

CAD
Technology Assessment Institute: Summit on CT Dose

Outline

• Application domains
  – Stroke imaging
  – Vasospasm
  – Myocardial Imaging
  – Tumor Imaging

• Basic CT Perfusion Paradigm

• Neuro Perfusion
  – Motivation
  – Technique
  – Artifacts and Pitfalls
  – Dose Issues

• Myocardial Perfusion
  – Motivation
  – Technique
  – Artifacts and Pitfalls
  – Dose Issues
Basic Paradigm

Observe dynamic blood flow as the contrast washes in and out.

Reference Curve (AIF, LV)

Normal tissue

Ischemic tissue

Time

HU
Parameterization

\[ \text{CBF} = \frac{\text{CBV}}{\text{MTT}} \]
Density = [Iodine] = Blood Flow

SNR and CNR


Stenosis and Blood Flow

![Graph showing the relationship between percent stenosis and flow at rest and stress.](Image)
Two mechanisms: **Flow-dependence and steal**
Main Challenges

• Too many technologies
  – CT scanners
  – Processing algorithms
• CNR and SNR are low
• Dose can be very high
• Clinical applications are still being worked out

Other than that, life is good!
<table>
<thead>
<tr>
<th>CT Technologies</th>
<th>Scanner</th>
<th>Pro</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-source</td>
<td>Widely available Cheap(er)</td>
<td>Slow Poor Z-axis coverage</td>
</tr>
<tr>
<td></td>
<td>Dual Source</td>
<td>Fast</td>
<td>Z-axis coverage Temporal inhomogeneity</td>
</tr>
<tr>
<td></td>
<td>Wide-area (320 MDCT)</td>
<td>Temporal homogeneity</td>
<td>Slower High Dose</td>
</tr>
<tr>
<td></td>
<td>2nd Gen Dual Source</td>
<td>Fast! Better Z-axis coverage</td>
<td>Still not full coverage $$</td>
</tr>
<tr>
<td></td>
<td>Triple Source 640 MDCT</td>
<td>5 milliseconds, Whole heart</td>
<td>In my dreams</td>
</tr>
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</table>
Low CNR and SNR

Area 2.35 cm
Avg 36.32 HU
Dev 9.781

36 HU
44 HU
MRP vs. CTP: Single pixel

Gray Matter

White Matter
MRP vs. CTP: Larger pixel size

Must thicken the slice and aggregate pixels for good CNR and SNR

Gray Matter

White Matter
Neuro Perfusion CT
Central Dogma: Diffusion-Perfusion Mismatch

Can CT show both the core and the penumbra of the infarct?

- **Diffusion Abnormality**
  - Permanently infarcted
  - Infarct core or dead tissue
- **Perfusion Abnormality**
  - Overall tissue at risk
  - Includes the core
- **(Perfusion – Diffusion)**
  - Potentially salvageable Tissue
  - Ischemic penumbra
**Acute Stroke Protocol**

- **Non-contrast Head CT**
  - **Not ischemic stroke** (Hemorrhage, Tumor, Hydro)
  - **Stroke**: CTA, CTP(+/-) (Loss of G/W, Dense vessel)

- **MR with Diffusion**
  - MRA(+/-)
  - MRP (+/-)

- **< 3 hours IV tPA**
- **< 6 hours IA Therapies**
- **< 9 hours Hypertensive Tx Hyperbaric Oxygen**
MGH Single Slab Perfusion Protocol

- Perfusion (single slab, cine)
  - 80 kVp 200 mA, 1 second rotation, 8 x 5 mm slices
  - Phase I (cine): 1 image every second for 40s (0.5s recon interval)
  - Phase II (axial): 1 image every 3 seconds for 27 s
  - Total duration = 67 s
  - Total X-ray exposure = 49 s
- CTDIvol = 470 mGy
- DLP = 1890 mGy-cm
- CTP protocol well within the 0.5 Gy CTDI (vol)
- Further 25% reduction with 150mA
Large Mismatch between DWI and MTT
DWI
**Radiation Dose**

Day 37 after 1\textsuperscript{st} CTP: four CTA/CTP and two DSA exams in 2 weeks

120 kV, 100 mAs, and 50 rotations

*Eur Radiol (2005) 15:41–46*
FDA Investigates the Safety of Brain Perfusion CT

On October 8, 2009, the US Food and Drug Administration (FDA) issued an initial notification regarding a safety investigation of facilities performing brain perfusion CT (PCT) scans. This alert indicated that the FDA had become aware of radiation overexposures during PCT imaging performed to diagnose stroke at a single, particular facility. Because of incorrect settings on the CT scanner console, more than 200 patients over a period of 18 months received radiation doses that were approximately 8 times the expected level. While this event involved a single kind of diagnostic test at 1 facility, the magnitude of these overdoses and their impact on the affected patients were significant. About 40% of the patients lost patches of hair as a result of the overdoses.

This episode highlights the importance of accurate dose indices and prompt, effective action by the FDA to address the issue. These indices include the volumetric CT dose index (CTDI_{vol}) and the dose-length product (DLP). The CTDI_{vol}, which was introduced to take into account the pitch of helical acquisitions, represents the average dose delivered within the reconstructed section, and is calculated as the weighted CTDI divided by the pitch. The DLP is the CTDI_{vol} multiplied by the scan length expressed in centimeters. It gives an indication of the energy imparted to organs, and can be used to assess overall radiation burden associated with a CT study. CT scanners now routinely record the CTDI_{vol} and, in some cases, the DLP. Although the CTDI_{vol} is not the dose to a specific patient, it is an index of the average radiation dose from a CT series. For each protocol selected, and for each patient, the dose indices displayed on the control panel should be carefully monitored and determined to be within a reasonable range to prevent accidental overexposure. Radiologists and technologists should also become acquainted with dose modulation software and, in the immediate future, with iterative reconstruction algorithms, which can replace filtered beam technique and decrease image noise at a lower radiation dose.
**CTP Dose**

- Low kVp is desirable
  - 80 kVp standard
  - Less radiation dose
  - More iodine conspicuity
- Low mAs is sufficient
  - < 200
  - As low as 100; “roadmap”
- Epilation threshold
  - ~ 3 Gy, ~ 3 wk delay
  - If CTP is 8x the .5 Gy max, dose at least 4 Gy!
## CT Perfusion Dose vs kVp

<table>
<thead>
<tr>
<th>kVp</th>
<th>mA</th>
<th>t</th>
<th>CTDI</th>
<th>Effective dose (mSv)</th>
<th>n Rot</th>
<th>Total organ dose (mGy)</th>
<th>Total Effective dose (mSv)</th>
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<tbody>
<tr>
<td>80</td>
<td>200</td>
<td>1</td>
<td>16.1</td>
<td>0.19</td>
<td>40</td>
<td>644</td>
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<td>100</td>
<td>200</td>
<td>1</td>
<td>28.6</td>
<td>0.35</td>
<td>40</td>
<td>1144</td>
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<tr>
<td>120</td>
<td>200</td>
<td>1</td>
<td>43.4</td>
<td>0.55</td>
<td>40</td>
<td>1736</td>
<td>22</td>
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<tr>
<td>140</td>
<td>200</td>
<td>1</td>
<td>59.6</td>
<td>0.67</td>
<td>40</td>
<td>2384</td>
<td>26.8</td>
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Cardiac Perfusion CT
Perfusion defect

Metabolic disorders

Diastolic dysfunction

Systolic dysfunction

EKG changes

Chest pain

Myocardial infarction

Nesto RW, Kowalchuk GJ. The ischemic cascade: temporal sequence of hemodynamic, electrocardiographic and symptomatic expressions of ischemia. *Am J Cardiol.* 1987;59:23C-30C.
<table>
<thead>
<tr>
<th></th>
<th>EKG</th>
<th>Echo</th>
<th>CT</th>
<th>MR</th>
<th>SPECT</th>
<th>PET</th>
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<tr>
<td>Plaque</td>
<td></td>
<td>+/-</td>
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<tr>
<td>Perfusion defect</td>
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<tr>
<td>Metabolic disorders</td>
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<tr>
<td>Diastolic dysfunction</td>
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<tr>
<td>Systolic dysfunction</td>
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<td>+</td>
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<tr>
<td>Electrical changes</td>
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<tr>
<td>Chest pain</td>
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<td></td>
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<tr>
<td>Myocardial infarction</td>
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<td>+</td>
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</table>
Reference Standard: Nuclear Medicine

- Expensive
- Dose heavy
- Artifact prone
- Low spatial resolution
- Low temporal resolution

Short-axis SPECT Image
Considerations for Stress Perfusion CT

**Stress Agent**
- Method?
- Effects on physiology?

**Contrast**
- Agent?
- Timing?
- Rate, dose?

**CT Protocol**
- Temporal resolution?
- Z-axis coverage?
- Radiation dose, ECG gating?
- Scan order?
- Dual Energy?

**Image Analysis**
- Qualitative?
- Quantitative?
- Semiquantitative?
- Reconstruction algorithm?
# Pharmacologic Stress Agents for CT

<table>
<thead>
<tr>
<th>Agent</th>
<th>Pro</th>
<th>Con</th>
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<tbody>
<tr>
<td>Exercise</td>
<td>Free</td>
<td>Motion</td>
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<tr>
<td>Dobutamine</td>
<td></td>
<td>Lower Sn, Sp, Provokes ischemia, Tachycardia</td>
</tr>
<tr>
<td>Adenosine</td>
<td>Cheap(er), Good Sn/Sp</td>
<td>Mild Tachycardia</td>
</tr>
<tr>
<td>Dipyridamole</td>
<td>Cheap, Good Sn/Sp</td>
<td>Tachycardia</td>
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<tr>
<td>Regadenoson/binadenoson</td>
<td>Easy to dose $$</td>
<td>Prolonged dose effects</td>
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</table>
Technology Assessment Institute: Summit on CT Dose

MGH Scan Protocol

- Contrast bolus 60-80 cc @ 4 cc/sec
- ~5 minute Recovery period
- Adenosine Perfusion CT Scan

- Contrast bolus 60-80 cc @ 4 cc/sec
- ~10 minute Delay
- Resting CTA

- Delayed CT

Multiple variations possible

Retrospectively Gated

Prospectively Gated
Coregistered short-axis image sets

Stress

Rest

Delayed
Gating-related artifacts
Gating-related artifacts
Photon starvation artifact
Future Directions in CTP

Novel reconstruction techniques: Iterative

Dual-energy imaging
Iterative reconstruction

Filtered Back Projection B10 axial 65% R-R Stress

Iterative Reconstruction B10 axial 65% R-R Stress

Images courtesy Homer Pien, Ph.D., MBA & Synho Do, Ph.D. (MGH Cardiac Image Processing and Computations)
50 yo male, chest pain, 7 years s/p MI, LAD stent.

LAD-territory infarct:
- Wall thinning
- Fatty metaplasia
“Iodine Map” Delayed Enhanced

100 kV Image

140 kV Image

“Iodine only” Image
Conclusion

• CTP is exciting
  – “Time is muscle”
  – “Time is brain”
  – “Mismatch is brain”
• CTP is challenging
  – Many technologies
  – Low CNR and SNR
  – Potentially high dose
• The complexity can be managed
  – Use low kVP
  – Use sufficient temporal resolution
  – Don’t truncate the time opcification curve
• Many new promising developments