CT Perfusion: How to do it right

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Outline

• Basic CT Perfusion Paradigm

• CT Perfusion for Stroke Imaging
  – Motivation
  – Technique and protocol
  – Artifacts and Pitfalls
  – Dose Issues
AAPM 2011 Summit on CT Dose

Courtesy of Prof. Lee Schwamm, MGH
Time is Brain

Lost per minute

Neurons: $1.9 \times 10^6$
Synapses: $14 \times 10^9$
Myelin fibers: 7.5 miles

Saver JL, Stroke 2006; 37: 263-266

NEJM Feb 2006: del Zoppo

MHL/MGH
Rate of neuronal loss $\alpha CBF$

Ischemia = $f$ (flow vs. time)
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
AAPM 2011 Summit on CT Dose

**CTP Example**

- Small infarct
- Proximal occlusion
- Large mismatch
DWI: Post IA Tx
Key Questions in Stroke Imaging

• Brain Attack Protocol
  – IV tPA: Is there hemorrhage? (CT)
  – IA tx: Is there large vessel occlusion? (CTA)
  – IA tx: How much brain is already dead? (DWI)
    • Infarct “core”
    • < 1/3 MCA territory or <70-100 ml
  – Other mgmt: “True-at-risk” vs “benign oligemia”?

• Perfusion imaging CAN’T REPLACE MR DWI
  – but … if DWI is not available …
  – CT-CBF (not CBV!) is the next best test for “core”
MGH Neuroradiology Acute Ischemic Stroke Recommended Imaging Algorithm

NCCT

CTA

MR Capable?

Yes

No

CTP

Includes TIA

“Angina of the Brain”

Courtesy of Gil Gonzalez, MD
Basic Paradigm

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

- Reference Curve (AIF, LV)
- Normal tissue
- Ischemic tissue

HU vs. Time

Short-axis through LV
Parameterization

\[ \text{CBF} = \frac{\text{CBV}}{\text{MTT}} \]
Main Challenges

- Too many technologies and 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!
Low CNR and SNR

Time

HU

Area 2.35 cm²
Avg 36.32 HU
Dev 9.78

36 HU

44 HU
Single pixel intensity as a function of time

Gray Matter

White Matter

Dr. Bill Copen, MGH
Average intensity over time

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

Gray Matter

White Matter

CT

MR

WAC/MGH
Radiation Dose

Day 37 after 1st CTP: four CTA/CTP and two DSA exams in 2 weeks
120 kV, 100 mAs, and 50 rotations

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
kVp Pitfall: Tissue spectral response

Iodine contrast

Brain

keV

Hu
CT Perfusion Dose vs kVp

- Low kVp is desirable
- 80 kVp standard
  - Less radiation dose
  - More iodine conspicuity

<table>
<thead>
<tr>
<th>kVp</th>
<th>mA</th>
<th>CTDI (mGy)</th>
<th>Eff dose (mSv)</th>
<th>Num Rot</th>
<th>Total organ dose (mGy)</th>
<th>Total Effective dose (mSv)</th>
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</thead>
<tbody>
<tr>
<td>80</td>
<td>200</td>
<td>16.1</td>
<td>0.19</td>
<td>40</td>
<td>644</td>
<td>7.6</td>
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<tr>
<td>100</td>
<td>200</td>
<td>28.6</td>
<td>0.35</td>
<td>40</td>
<td>1144</td>
<td>14</td>
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<tr>
<td>120</td>
<td>200</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>59.6</td>
<td>0.67</td>
<td>40</td>
<td>2384</td>
<td>26.8</td>
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</table>
mAs Pitfall

- CT Perfusion is NOT, and should not be a standard head CT protocol
- 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!
Sampling Frequency Pitfall

- Acquire adequate baseline
- Brain transit time (~5s) is fast
- Need at least 1.0s to 1.5s sampling in the arterial phase
- Slower sampling OK in venous phase
- Do not try to beat the Nyquist limit
Sampling Duration Pitfall: Time-Opacification Curve Truncation with Slow Flow
**CTP Interpretation Pitfalls**

- Reperfusion is necessary but not sufficient for a good outcome
- Collateral circulation strongly influences treatment response
- Quantification of perfusion is not validated
- Core infarct volume is the best surrogate marker for patient selection
MGH experience, 2004-2008

Good Outcome vs. Recanalization

3-month mRS≤2 (%)

P=2x10⁻⁶

64%

0

22%

0-1

2A

TICI score

2B-3

No reperfusion

Greater reperfusion
Mortality vs. Recanalization

- 0-1 TICI score: 64%  
- 2A TICI score: 36%  
- 2B-3 TICI score: 9%

P=0.0002

No reperfusion  Greater reperfusion
• Reperfusion is not sufficient for a good outcome
Revascularization = Good Outcome??

<table>
<thead>
<tr>
<th></th>
<th>IMS II</th>
<th>PROACT II (treatment arm)</th>
<th>Multi MERCI</th>
<th>Penumbra</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>81</td>
<td>121</td>
<td>164</td>
<td>125</td>
</tr>
<tr>
<td>age (yrs)</td>
<td>64±11.5</td>
<td>64±14</td>
<td>68±16</td>
<td>63.5±13.5</td>
</tr>
<tr>
<td>NIHSS</td>
<td>19±5.3</td>
<td>17 (5-27)</td>
<td>19 (15-23)</td>
<td>17.6±5.2</td>
</tr>
<tr>
<td>% TIMI 2/3 recanalization</td>
<td>60</td>
<td>66</td>
<td>69.5</td>
<td>81.6</td>
</tr>
<tr>
<td>% good outcome (mRS≤2, 90 dd)</td>
<td>46</td>
<td>40</td>
<td>36</td>
<td>25</td>
</tr>
<tr>
<td>% mortality (90 dd)</td>
<td>16</td>
<td>25</td>
<td>34</td>
<td>32.8</td>
</tr>
</tbody>
</table>

↑Recanalization = ↓Outcomes
Time is Brain???

8 HOURS POST-ICTUS

79 year old female with right hemiparesis and seizure: ICA-T occlusion
Time is Brain???

2.5 HOURS POST-ICTUS

74 year old male with right hemiparesis and aphasia: ICA-T occlusion
Why such variability in response?

- Different people’s neurons behave differently to ischemia
- The collateral circulation, which varies enormously, strongly influences treatment response
Infarct Size = Rate x Time

A. Average Neuronal Loss

B. Variable Neuronal Loss

Courtesy of Reza Hakimelahi, MD
Collateral circulation

Koroshetz / Gonzalez
In: Acute Ischemic Stroke Imaging and Intervention 2006

Christoforidis AJNR 26:1789–1797, August 2005
The Ischemic Penumbra

[Diagram of a human head with the terms 'Penumbra' and 'Core' labeled, courtesy of Dr. Gil González]
Selection for IAT

- PWI/DWI mismatch not discriminatory
- More important question: How much is dead on arrival ("core")?
- An acute infarct volume threshold of 70-100 ml has a high specificity for predicting a poor outcome\(^1,\)\(^2\)

\(^1\)Sanak et al. *Neuroradiology* 2006; 48: 632-9
\(^2\)Yoo et al. *Stroke* 2009 Jun;40(6):2046-54
Example: Admission CT and CTA
Admission CT Perfusion

CBF  CBV  MTT
CTA Post Intra-arterial Tx
Post Intra-arterial Tx
CTP Post Intra-arterial Tx

CBF  CBV  MTT
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 low mAs
  – Use sufficient temporal resolution
  – Don’t truncate the time optimization curve
  – Don’t over-interpret CTP maps
**Bottom Line**

- Perfusion cannot replace DWI
- Perfusion shows the state of plumbing and not tissue viability
- When DWI is not available/feasible, in conjunction with other parameters, CTP can be used to guide decision making