Eye lens dose from brain perfusion CT exams

Di Zhang

Toshiba America Medical Systems
Disclosure

- Current employee of Toshiba America Medical Systems
CT brain perfusion

- Evaluate cerebral perfusion defects for suspected stroke patients
- Important tool to monitor blood-brain barrier
- Repeatedly exposing one location of the head to monitor contrast uptake and wash-out
Concern about deterministic effects

- Radiation dose
- Peak skin dose:
  - Erythema (skin reddening) and epilation (hair loss) complications
- Eye lens dose:
  - Cataractogenensis
Concern about deterministic effects

- Started from medias
  - Hospitals in Los Angeles, Atlanta, etc
Eye lens dose management is important

- Retrospective estimation
- Correlation with existing CT dose metrics
- Reduction strategies
Eye lens dose management

- Retrospective estimation
- Correlation with existing metrics
- Reduction strategies
Estimating eye lens dose

- Monte Carlo simulations
  - CT source model
  - Patient model
CT source model

- **Spectra**
  - Function of beam energy

- **Geometry**
  - Fan angle, beam profile

- **Filtration**
  - Bowtie filter (typically proprietary)
  - Other added filtration (also proprietary)

- **Data comes from:**
  - Manufacturer
  - Equivalent Source Methods (e.g. Turner et al. Med Phys 2009)
    - Measured values (HVL, bowtie profile)
    - Calculations to get “equivalent” spectra and bowtie
Estimating eye lens dose

- Monte Carlo method based simulations (MCNPX)
  - CT source models for 64 slice scanners from all four manufactures
    - Toshiba Aquilion 64
Estimating eye lens dose

- Monte Carlo method based simulations (MCNPX)
  - CT source models for 64 slices scanners from four major manufactures
    - Toshiba Aquilion 64
    - Siemens Sensation 64
Estimating eye lens dose

- Monte Carlo method based simulations (MCNPX)
  - CT source models for 64 slice scanners from all four manufactures
    - Toshiba Aquilion 64
    - Siemens Sensation 64
    - GE VCT
Estimating eye lens dose

- Monte Carlo method based simulations (MCNPX)
  - CT source models for 64 slices scanners from all four manufactures
    - Toshiba Aquilion 64
    - Siemens Sensation 64
    - GE VCT 64
    - Phillips Brilliance 64
Patient model

- **Voxelized Models**
  - Based on actual patient images
  - Identify radiosensitive organs – usually manually
    - Location, size, composition, and density defined for each organ

- Different age, gender, and sizes
Patient model

- **GSF models** (Petoussi-Henss N, Zankl M et al, 2002)
  - 4 adults (Irene, Donna, Golem, and Frank)
Simulation experiments

- To estimate eye lens dose from brain perfusion scan:
  - All 4 scanners, all 4 patients
  - at all 4 tube voltage settings (4 x 4 x 4 simulations)
  - Using the widest collimation
  - Cover the eye lenses
  - No table movement
Results

- **Eye lens dose (mGy/100mAs)**

Di Zhang, et al, Med Phys, 40 (9), 2013
So……?

- Estimate scanner and protocol specific eye lens dose for CT brain perfusion exams

- For example, AAPM brain perfusion protocols
AAPM protocols

American Association of Physicists in Medicine

CT Scan Protocols

Available Protocols

Adult Protocols

- Lung Cancer Screening CT (updated 07/03/2015) [Give Feedback]
- Routine Adult Chest-Abdomen-Pelvis CT (addes 02/20/2014) [Give Feedback]
- Routine Adult Chest CT (added 11/20/2012) [Give Feedback]
- Routine Adult Abdomen/Pelvis CT (added 10/17/2012) [Give Feedback]
- Routine Adult Head CT (added 06/01/2012) [Give Feedback]
- Routine Adult Brain Perfusion (updated 05/22/2012) [Give Feedback]
## AAPM protocols

<table>
<thead>
<tr>
<th>Scanner/Mode</th>
<th>kVp</th>
<th>bowtie</th>
<th>Nominal collimation (total) in mm</th>
<th>mAs/rotation</th>
<th>No. of rotations</th>
<th>total mAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens Sensation 64</td>
<td>80</td>
<td>general</td>
<td>24 x 1.2 (28)</td>
<td>270</td>
<td>40</td>
<td>10800</td>
</tr>
<tr>
<td>GE VCT axial mode</td>
<td>80</td>
<td>head</td>
<td>64 x 0.625 (40)</td>
<td>150</td>
<td>22</td>
<td>3300</td>
</tr>
<tr>
<td>GE VCT cine mode</td>
<td>80</td>
<td>head</td>
<td>64 x 0.625 (40)</td>
<td>150</td>
<td>45</td>
<td>6750</td>
</tr>
<tr>
<td>Philips Brilliance 64</td>
<td>80</td>
<td>general</td>
<td>32 x 1.25(40)</td>
<td>125</td>
<td>30</td>
<td>3750</td>
</tr>
</tbody>
</table>
## AAPM protocols

<table>
<thead>
<tr>
<th>Scanner/ mode</th>
<th>Siemens Sensation 64</th>
<th>GE VCT axial mode</th>
<th>GE VCT cine mode</th>
<th>Philips Brilliance 64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye lens dose (mGy)</td>
<td>256</td>
<td>137</td>
<td>279</td>
<td>81</td>
</tr>
</tbody>
</table>
Eye lens dose management is important

- Retrospective estimation
- Correlation with existing metrics
- Reduction strategies
CT dose metrics

- $CTDl_{vol}$
  - Assume continuous scans with table incrementations
  - Overestimate dose to a point

$\text{CTDI}_{vol}$ normalized by true eye lens dose

Ratio of $\text{CTDI}_{vol}$ and simulated eye lens dose under each kVp on all four scanners for all four patients
CT dose metrics

- AAPM TaskGroup 111 (TG111) peak dose metric
  - Use a small chamber for point dose measurement
  - May provide better estimate to eye lens dose from brain perfusion scans
TG111 measurements normalized by true eye lens dose

Ratio of AAPM report No. 111 measurement and simulated eye lens dose under each kVp on all four scanners for all four patients

Di Zhang, et al, Med Phys, 40 (9), 2013
Outline

- Estimation
- Correlation with existing metrics
- Reduction strategies
Explore dose reduction strategies

- Lowering kVp or mAs, IR (universal methods)
- Bismuth shielding
- Organ based tube current modulation
Explore dose reduction strategies

- Simply the geometry
  - Scan location
  - Gantry tilt
Explore dose reduction strategies

- Move scan location away every 0.5 cm.
- Tilt gantry angle every 5 degree.
Dose reduction strategies

- Moving scan location away (half beam width 1.6 cm)

Eye lens dose as a function of scan location at 120kVp, 4500 total mAs for Siemens Sensation 64 scanner

Distance from eye lens, which ranges from -0.5 cm to 0.5 cm

Dose reduction strategies

- Tilting gantry angle

Conclusions
Conclusion (1)

- Accurately estimate eye lens dose from CT brain perfusion exam
  - Protocol design
  - Dose estimate
Conclusion (2)

- Understand the performance of common tools in terms of estimating eye lens dose
  - CTDI overestimates dose, conservative estimation
  - TG111 is more accurate, but not currently available on console
  - Still not dose to patient
Conclusion (3)

- Strategies to reduce eye lens dose
  - Moving the scan location away
  - Tilting the gantry angle
CT perfusion imaging requires repeatedly exposing one location of the head in order to:

1. Improve low contrast resolution within the brain parenchyma (8%)
2. Maximize the spatial resolution within the brain parenchyma (0%)
3. Monitor brain tumor growth over a short period of time (2%)
4. Monitor the flow of cerebrospinal fluid (14%)
5. Monitor the uptake and wash-out of iodinated contrast (76%)
CT perfusion imaging requires repeatedly exposing one location of the head in order to:

1. Improve low contrast resolution within the brain parenchyma
2. Maximize the spatial resolution within the brain parenchyma
3. Monitor brain tumor growth over a short period of time
4. Monitor the flow of cerebrospinal fluid
5. Monitor the uptake and wash-out of iodinated contrast

The scanner reported CTDIvol values for the Brain Perfusion protocols posted on the AAPM website range actually:

62%  1. Overestimate the patient eye lens dose by at least 20%

15%  2. Overestimate the patient eye lens dose by just under 10%

15%  3. An accurate estimate of patient eye lens dose to within 10%

6%    4. Underestimate the patient eye lens dose by just under 10%

2%    5. Underestimate the patient eye/ lens dose by at least 20%
The scanner reported CTDIvol values for the Brain Perfusion protocols posted on the AAPM website range actually:

1. Overestimate the patient eye lens dose by at least 20%
2. Overestimate the patient eye lens dose by just under 10%
3. An accurate estimate of patient eye lens dose to within 10%
4. Underestimate the patient eye lens dose by just under 10%
5. Underestimate the patient eye lens dose by at least 20%