Eye lens dose from CT brain perfusion CT exams

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Disclosure

- Currently employee of Toshiba America Medical Systems

Background

CT brain perfusion

- Significant improvements in CT technology over the past decade
  - Multi-detector CT (4 -> 320 rows)
  - Improved temporal resolution (seconds -> ~0.3 sec per rotation)
- Led to increase in clinical utilization
  - Including brain perfusion CT

CT brain perfusion

- Evaluate cerebral perfusion defects for suspected stroke patients
  - Nature, age, mechanism, and potential reversibility
  - Within the critical therapeutic time window
- Important tool to evaluate brain tumors
  - Perfusion characteristics of brain neoplasm to determine malignant potential
  - Assess therapy response by monitoring changes of blood-brain barrier

CT brain perfusion scan flowchart

Concern about deterministic effects

- Radiation dose
- Peak skin dose:
  - Erythema (skin reddening) and epilation (hair loss) complications
- Eye lens dose:
  - Cataractogenesis
- Can be caused by improper protocol or operation

Concern about deterministic effects

- Started from medias
  - Hospitals in Los Angeles, Altanta, etc

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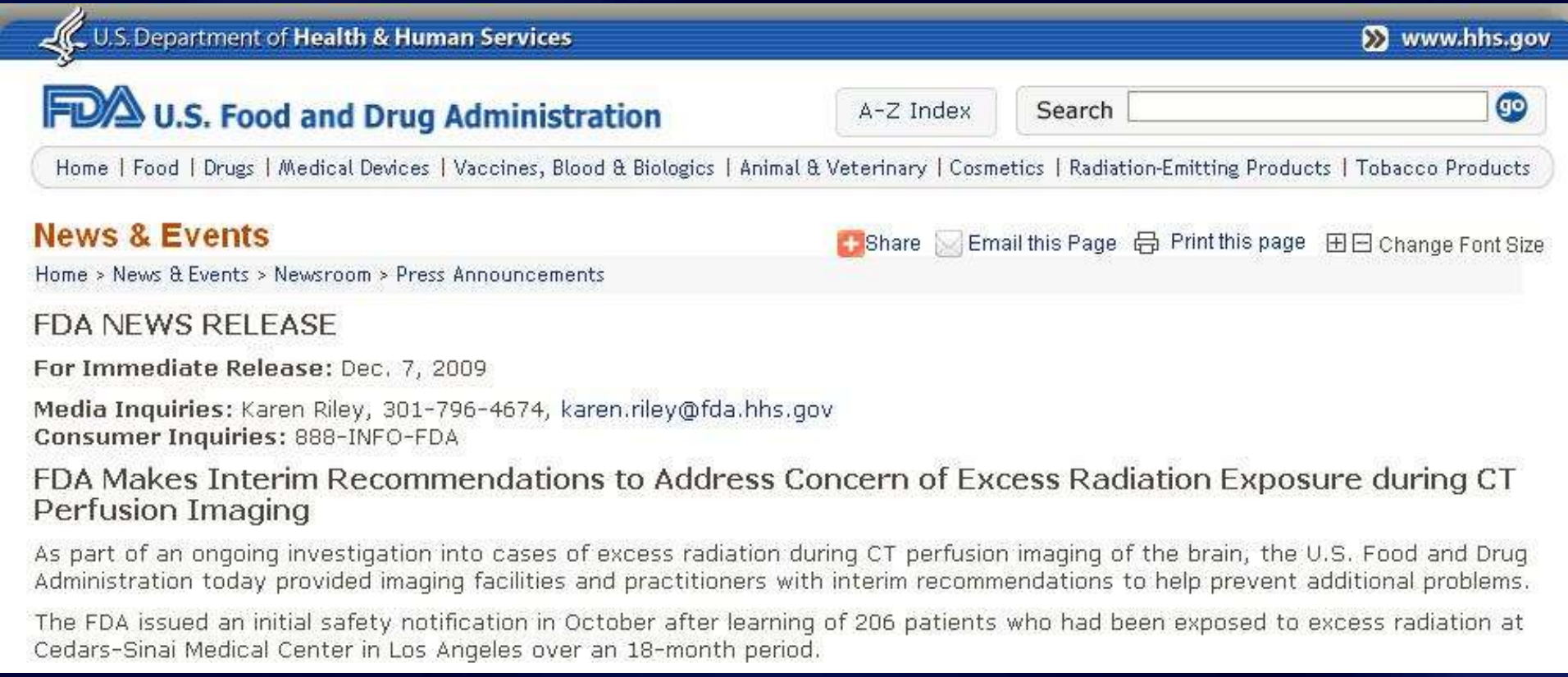
Update: Cedars-Sinai explains CT perfusion radiation overexposure

Concern about deterministic effects



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FDA NEWS RELEASE

For Immediate Release: Dec. 7, 2009

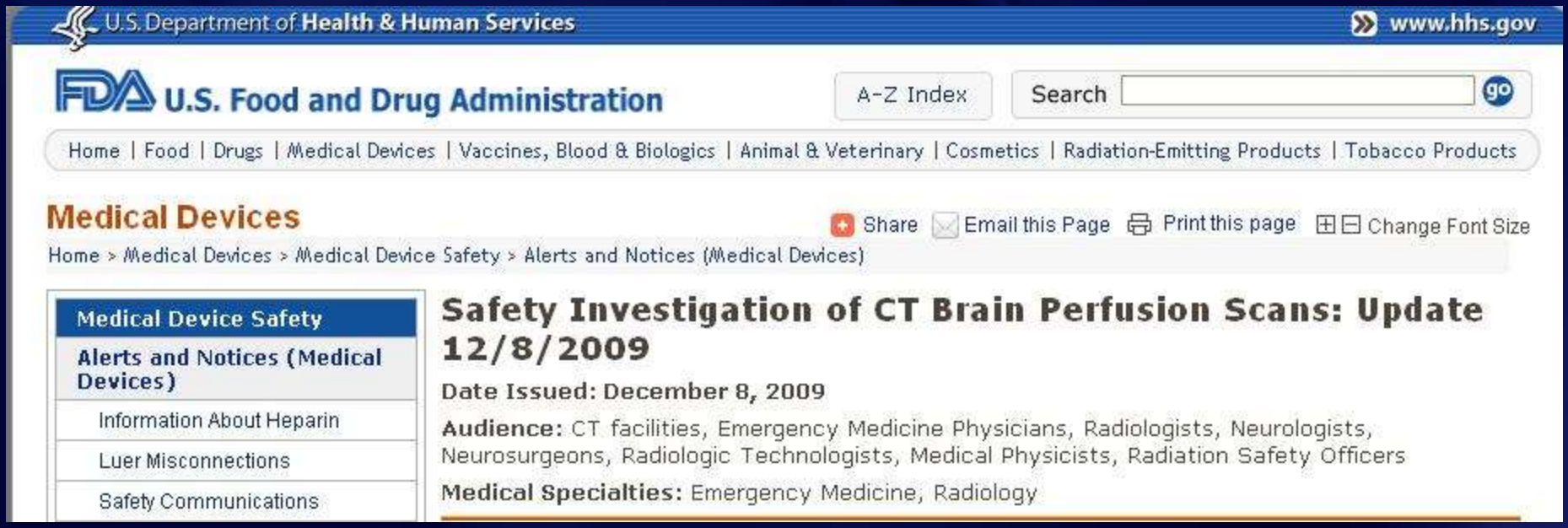
Media Inquiries: Karen Riley, 301-796-4674, karen.riley@fda.hhs.gov
Consumer Inquiries: 888-INFO-FDA

FDA Makes Interim Recommendations to Address Concern of Excess Radiation Exposure during CT Perfusion Imaging

As part of an ongoing investigation into cases of excess radiation during CT perfusion imaging of the brain, the U.S. Food and Drug Administration today provided imaging facilities and practitioners with interim recommendations to help prevent additional problems.

The FDA issued an initial safety notification in October after learning of 206 patients who had been exposed to excess radiation at Cedars-Sinai Medical Center in Los Angeles over an 18-month period.

Concern about deterministic effects



Concern about deterministic effects

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Radiation Safety

Radiation Dose Reduction

Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging

White Paper: Initiative to Reduce Unnecessary Radiation Exposure from Medical Imaging

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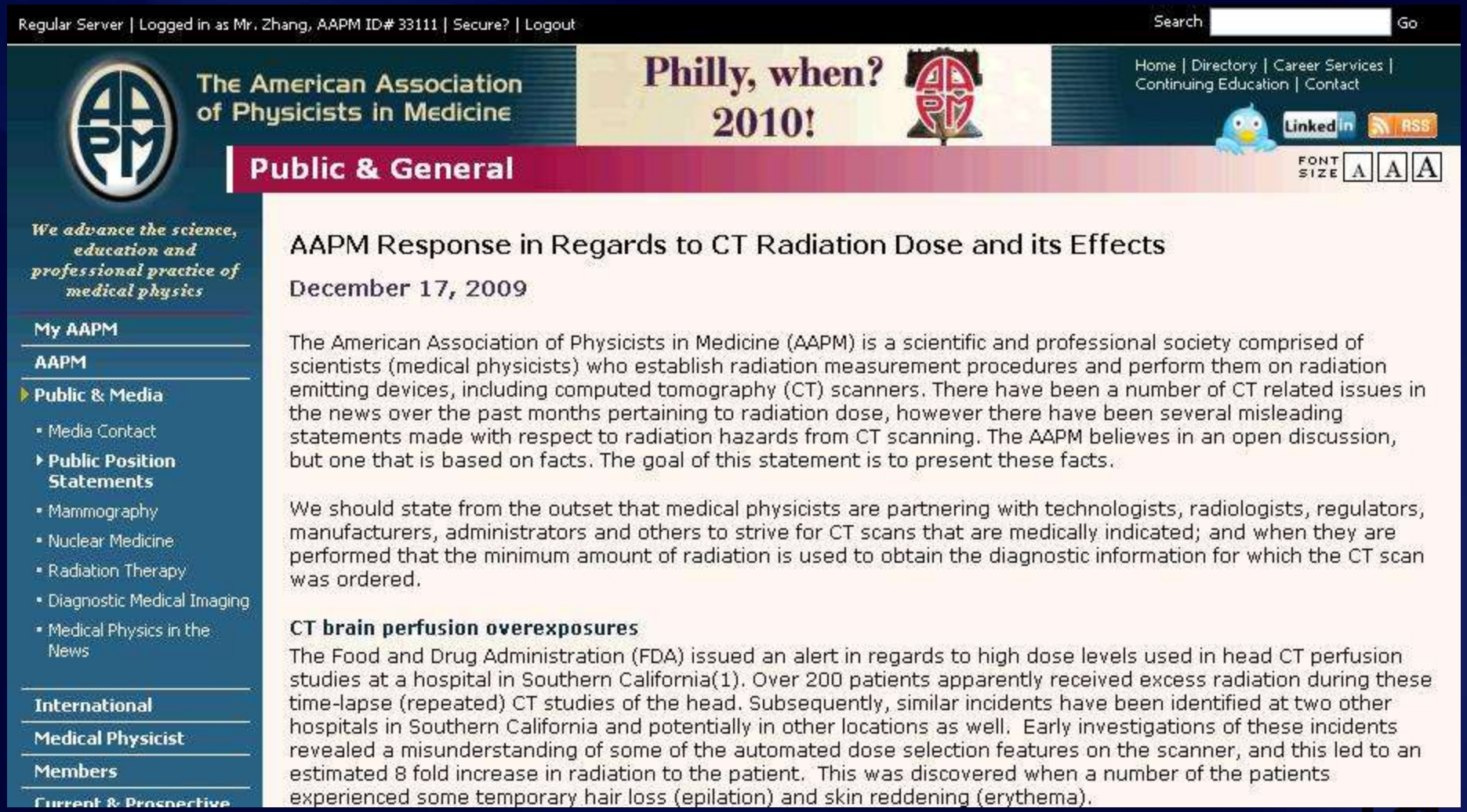
Executive Summary

Like all medical procedures, computed tomography (CT), fluoroscopy, and nuclear medicine imaging exams present both benefits and risks. These types of imaging procedures have led to improvements in the diagnosis and treatment of numerous medical conditions. At the same time,

Concern about deterministic effects



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Philly, when? 2010!

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AAPM Response in Regards to CT Radiation Dose and its Effects

December 17, 2009

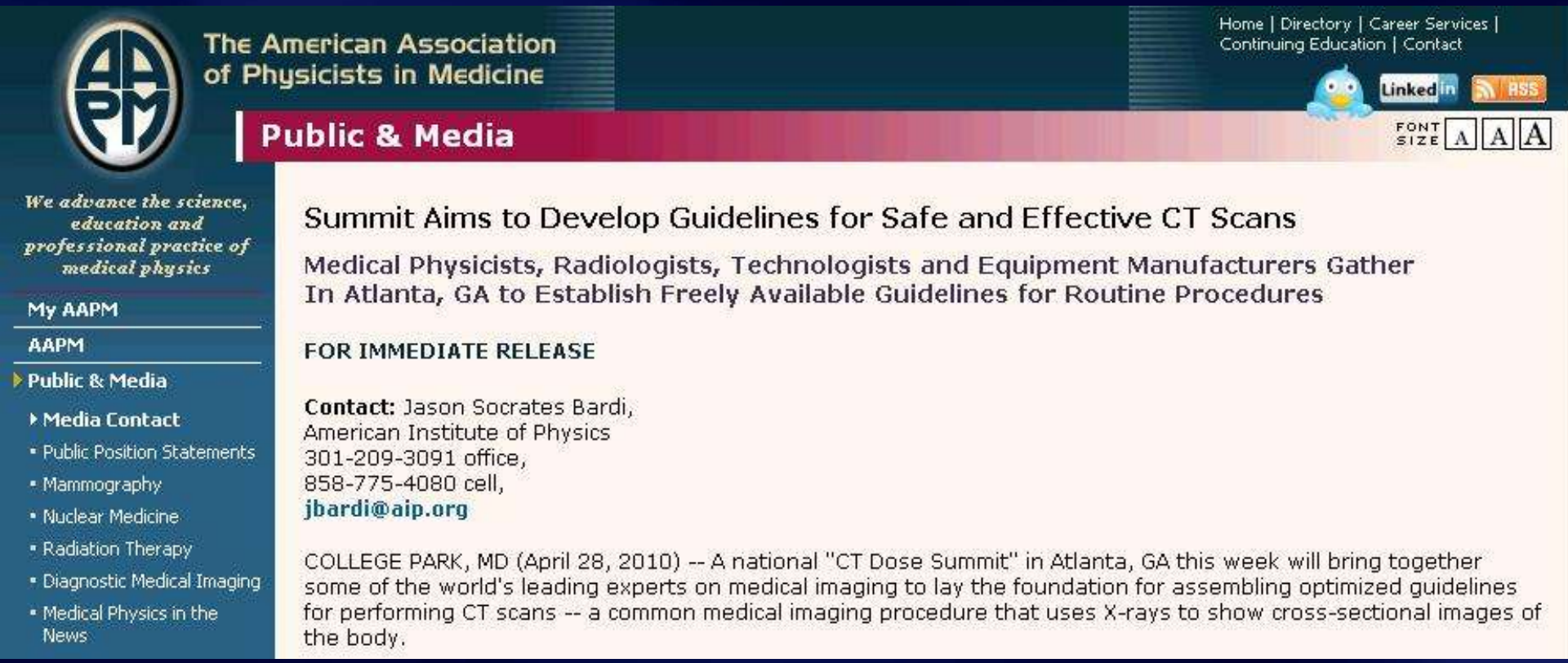
The American Association of Physicists in Medicine (AAPM) is a scientific and professional society comprised of scientists (medical physicists) who establish radiation measurement procedures and perform them on radiation emitting devices, including computed tomography (CT) scanners. There have been a number of CT related issues in the news over the past months pertaining to radiation dose, however there have been several misleading statements made with respect to radiation hazards from CT scanning. The AAPM believes in an open discussion, but one that is based on facts. The goal of this statement is to present these facts.

We should state from the outset that medical physicists are partnering with technologists, radiologists, regulators, manufacturers, administrators and others to strive for CT scans that are medically indicated; and when they are performed that the minimum amount of radiation is used to obtain the diagnostic information for which the CT scan was ordered.

CT brain perfusion overexposures

The Food and Drug Administration (FDA) issued an alert in regards to high dose levels used in head CT perfusion studies at a hospital in Southern California(1). Over 200 patients apparently received excess radiation during these time-lapse (repeated) CT studies of the head. Subsequently, similar incidents have been identified at two other hospitals in Southern California and potentially in other locations as well. Early investigations of these incidents revealed a misunderstanding of some of the automated dose selection features on the scanner, and this led to an estimated 8 fold increase in radiation to the patient. This was discovered when a number of the patients experienced some temporary hair loss (epilation) and skin reddening (erythema).

Concern about deterministic effects



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Summit Aims to Develop Guidelines for Safe and Effective CT Scans

Medical Physicists, Radiologists, Technologists and Equipment Manufacturers Gather In Atlanta, GA to Establish Freely Available Guidelines for Routine Procedures

FOR IMMEDIATE RELEASE

Contact: Jason Socrates Bardi,
American Institute of Physics
301-209-3091 office,
858-775-4080 cell,
jbardi@aip.org

COLLEGE PARK, MD (April 28, 2010) -- A national "CT Dose Summit" in Atlanta, GA this week will bring together some of the world's leading experts on medical imaging to lay the foundation for assembling optimized guidelines for performing CT scans -- a common medical imaging procedure that uses X-rays to show cross-sectional images of the body.

Concern about deterministic effects

CRCPD Pub. E-10-4

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CT Scan Protocols

Purpose | Questions | Role of the QMP | CT Dose-Check | Protocols | Lexicon | Education Slides

Available Protocols

Adult Protocols

- 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]

Eye lens dose management is important

- Accurately estimate eye lens dose from brain perfusion exams
- How well easily implementable CT metrics can predict eye lens dose
- Explore eye lens dose reduction strategies
- Optimize scanning protocols
- Ensure the Enforcement of the optimized protocols

Eye lens dose management is important

- Accurately estimate eye lens dose from brain perfusion exams
- How well easily implementable CT metrics can predict eye lens dose
- Explore eye lens dose reduction strategies
- Optimize scanning protocols
- Ensure the Enforcement of the optimized protocols

Outline

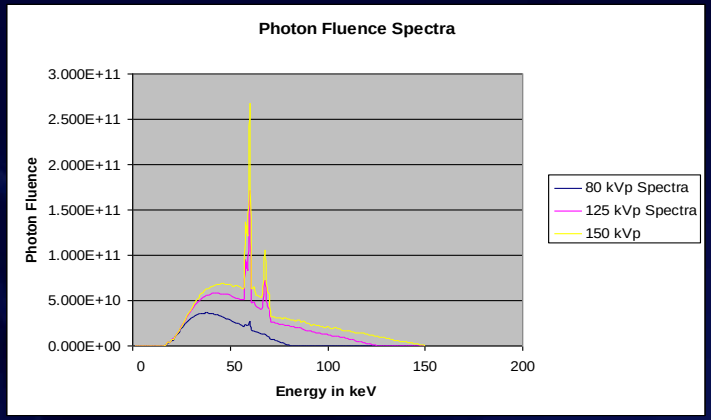
- Accurately estimate eye lens dose from brain perfusion exams
- Evaluate the prediction of skin and eye lens dose from dosimetry measurements
- Explore dose reduction strategies

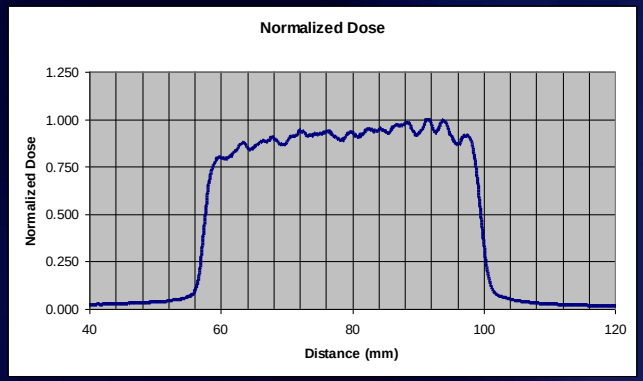
Estimating eye lens dose

- 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 Method (Turner 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

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Estimating eye lens dose

- Monte Carlo method based simulations (MCNPX)
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    - Toshiba Aquilion 64
    - Siemens Sensation 64
    - GE VCT 64
    - Phillips Brilliance 64

Patient model

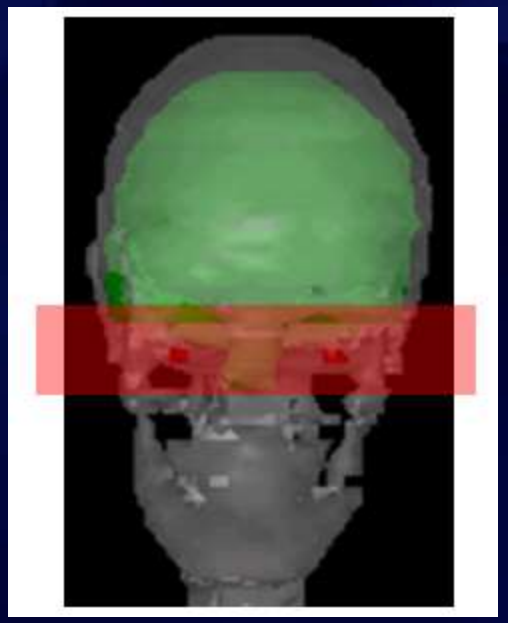
- Voxelized Models
  - Based on actual patient images
  - Identify radiosensitive organs – usually manually
    - Location, size, composition, and density defined for each organ
- Different age, gender, and sizes
- RPI, UFL, Duke, GSF, etc.

Patient model

- GSF models (Petoussi-Henss N, Zankl M et al, 2002)
  - All radiosensitive organs identified manually (ugh!)
  - 4 adults (Irene, Donna, Golem, and Frank)

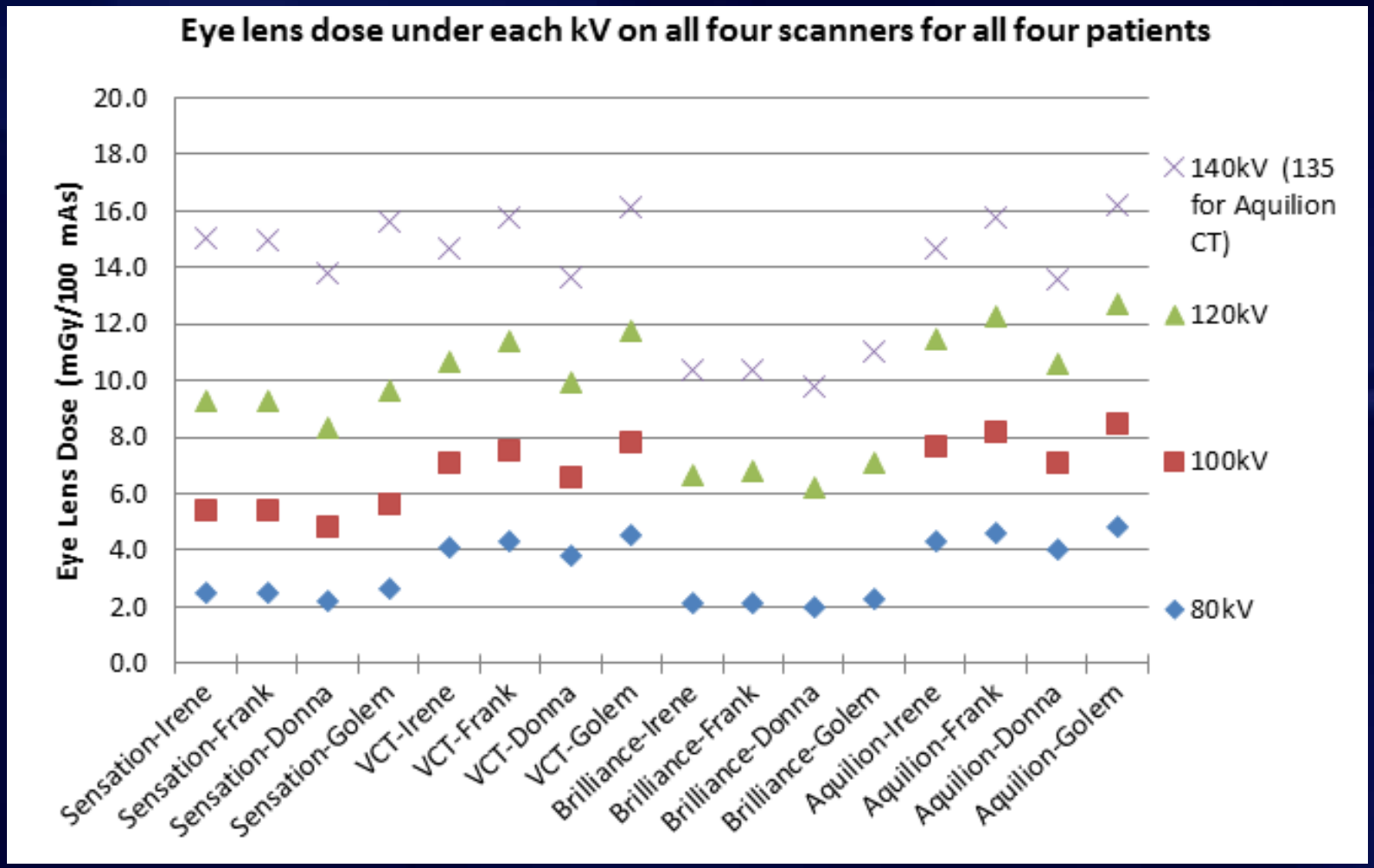
Simulation experiments

- 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)



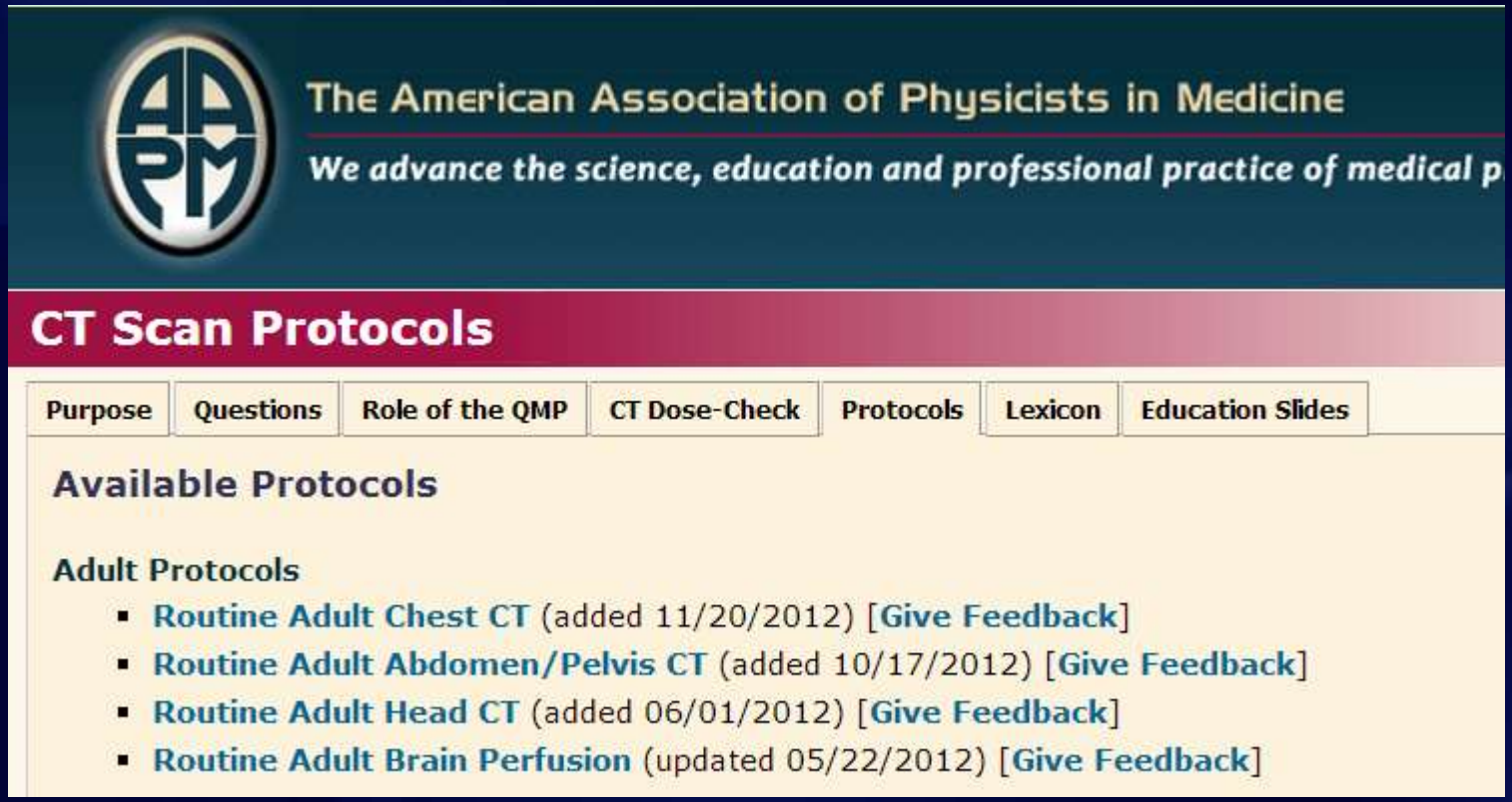
Di Zhang, et al, Med Phys, 40 (9), 2013

So……?

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

- For example, AAPM brain perfusion protocols

AAPM protocols



AAPM protocols

Scanner/Mode	kVp	bowtie	Nominal collimation (total) in mm	mAs/rotation	No. of rotations	total mAs
Siemens Sensation 64	80	general	24 x 1.2 (28)	270	40	10800
GE VCT axial mode	80	head	64 x 0.625 (40)	150	22	3300
GE VCT cine mode	80	head	64 x 0.625 (40)	150	45	6750
Philips Brilliance 64 Non-Jog mode	80	general	32 x 1.25(40)	125	30	3750

AAPM protocols

Scanner/ mode	Siemens Sensation 64	GE VCT axial mode	GE VCT cine mode	Philips Brilliance 64
Eye lens dose (mGy)	256	137	279	81

Calculate dose for other protocols

- Can be used by other institution as a tool to calculate eye lens dose for their scanning protocols
- Protocol design
- Retrospective dose estimates

Outline

- Accurately estimate peak skin and eye lens dose from neuro-perfusion examinations
- Evaluate the prediction of eye lens dose from easily implementable CT metrics
- Explore dose reduction strategies

CT dose metrics

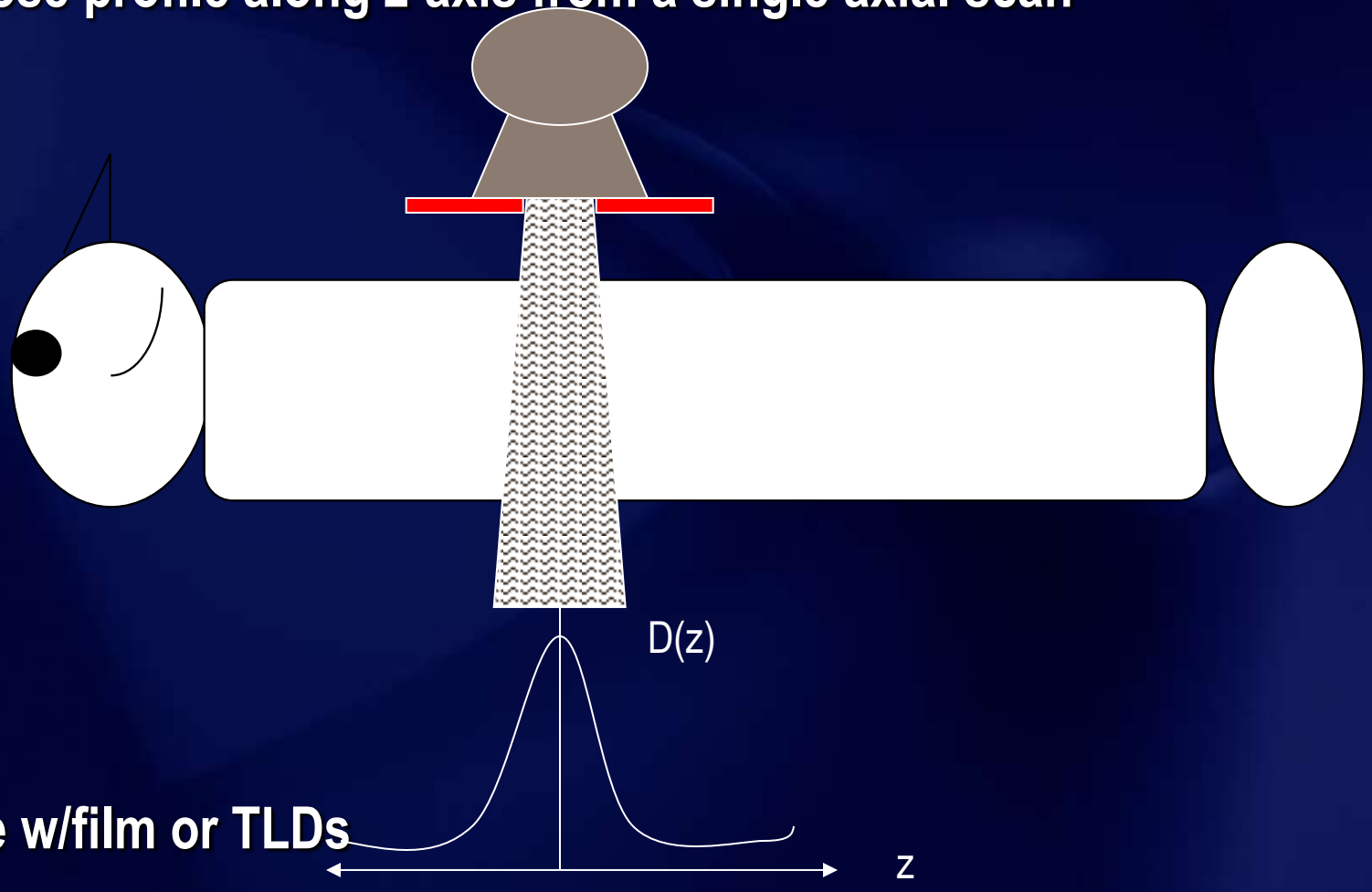
- Conventional Computed Tomography Dose Index ($CTDI_{vol}$)
  - Most widely used and reported on scanners

Total mAs 9229 Total DLP 3244 mGycm

	Scan	kV	mAs / ref.	CTDIvol mGy	DLP mGycm	TI s	cSL mm
Patient Position H-SP							
Head/NETopo	1	120	35 mA			4.2	0.6
HdSeq XC wo	2	120	214 / 240	37.08	640	2.0	1.2
Perfusion w	7	80	95	211.86	814	1.0	1.2
PreMonitoring	8	120	20	2.44	2	0.5	10.0
Contrast Monitoring	9	120	20	19.53	20	0.5	10.0
CTA Brain/Nck	17	120	308 / 335	43.39	1768	0.5	0.6

CT Dose Distribution along Z

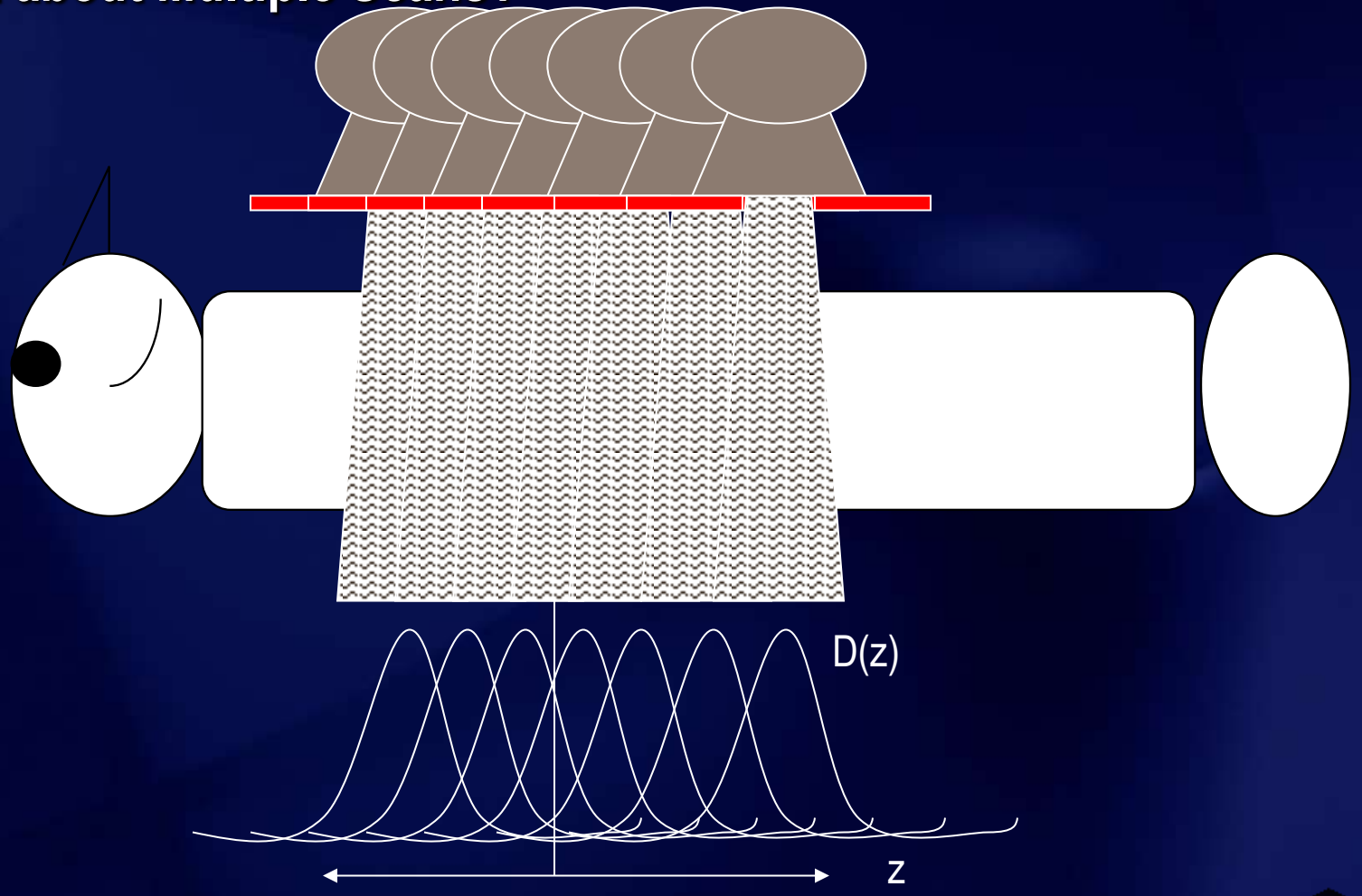
- D(z) = dose profile along z-axis from a single axial scan



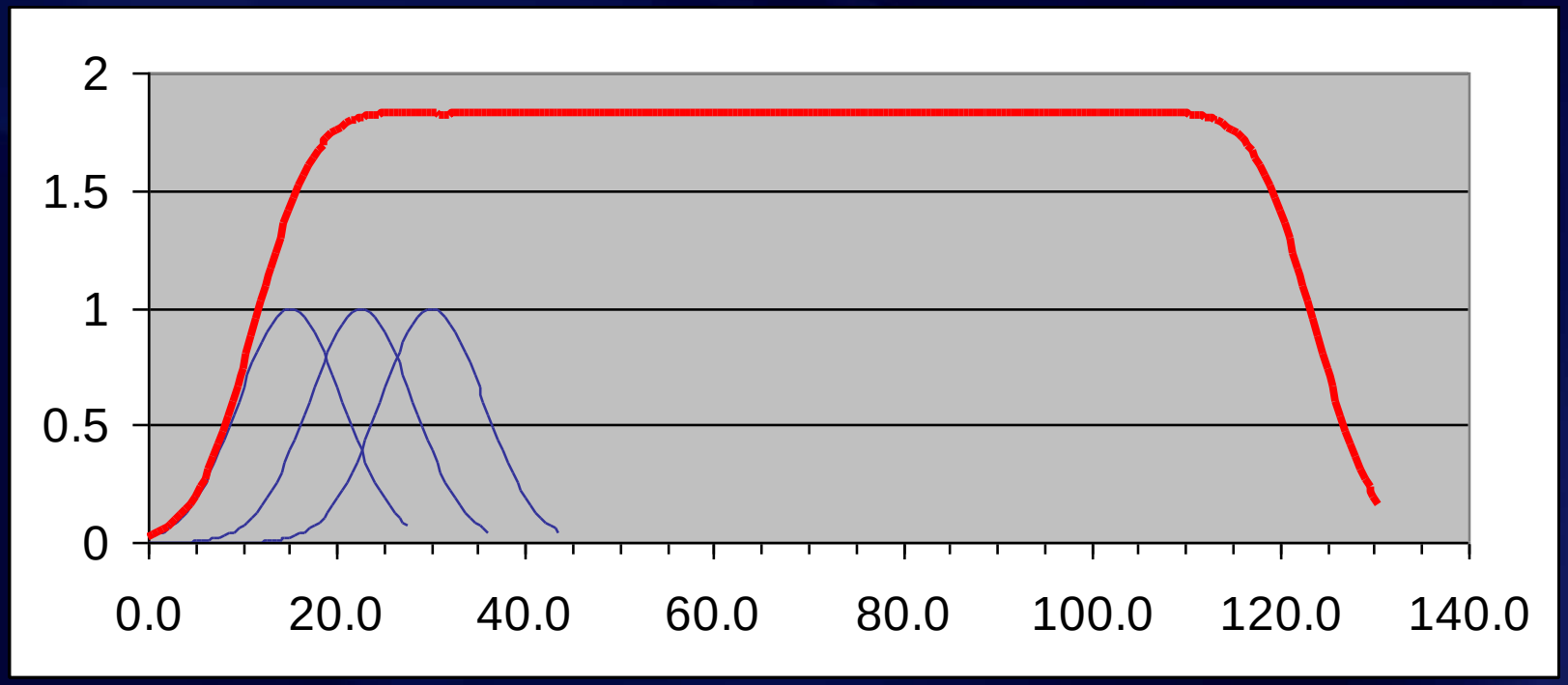
- Measure w/film or TLDs

CT Dose Distribution Along Z

- **What about Multiple Scans?**

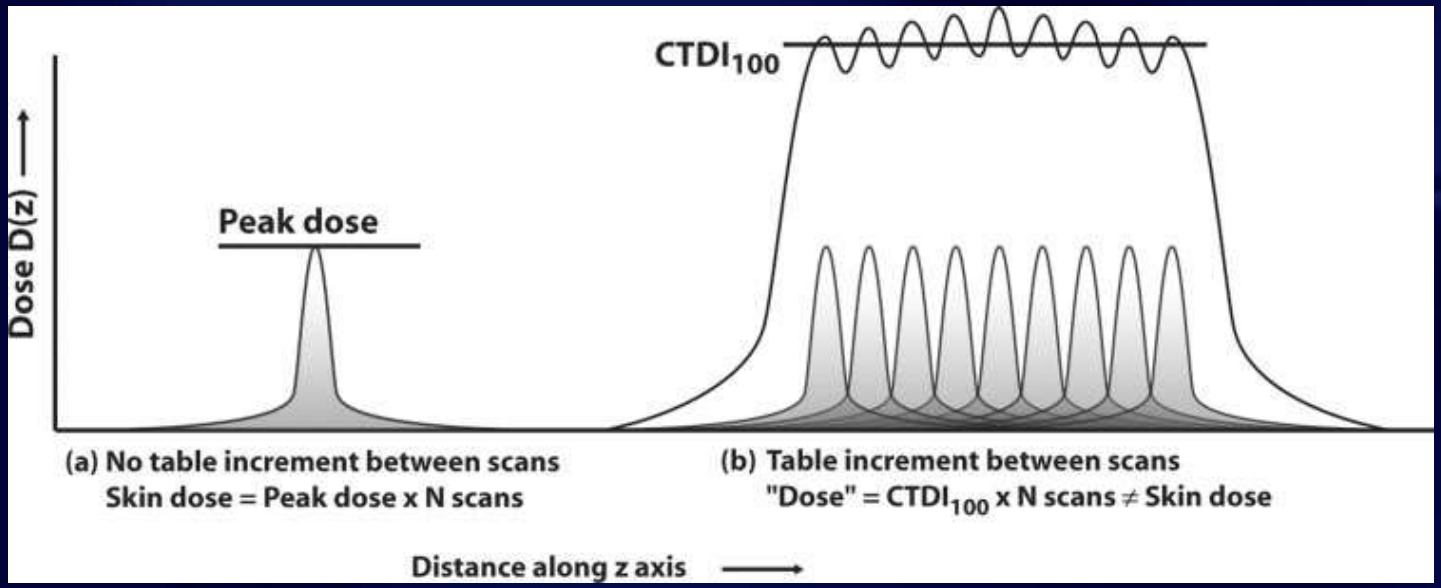


CT Dose Distributions



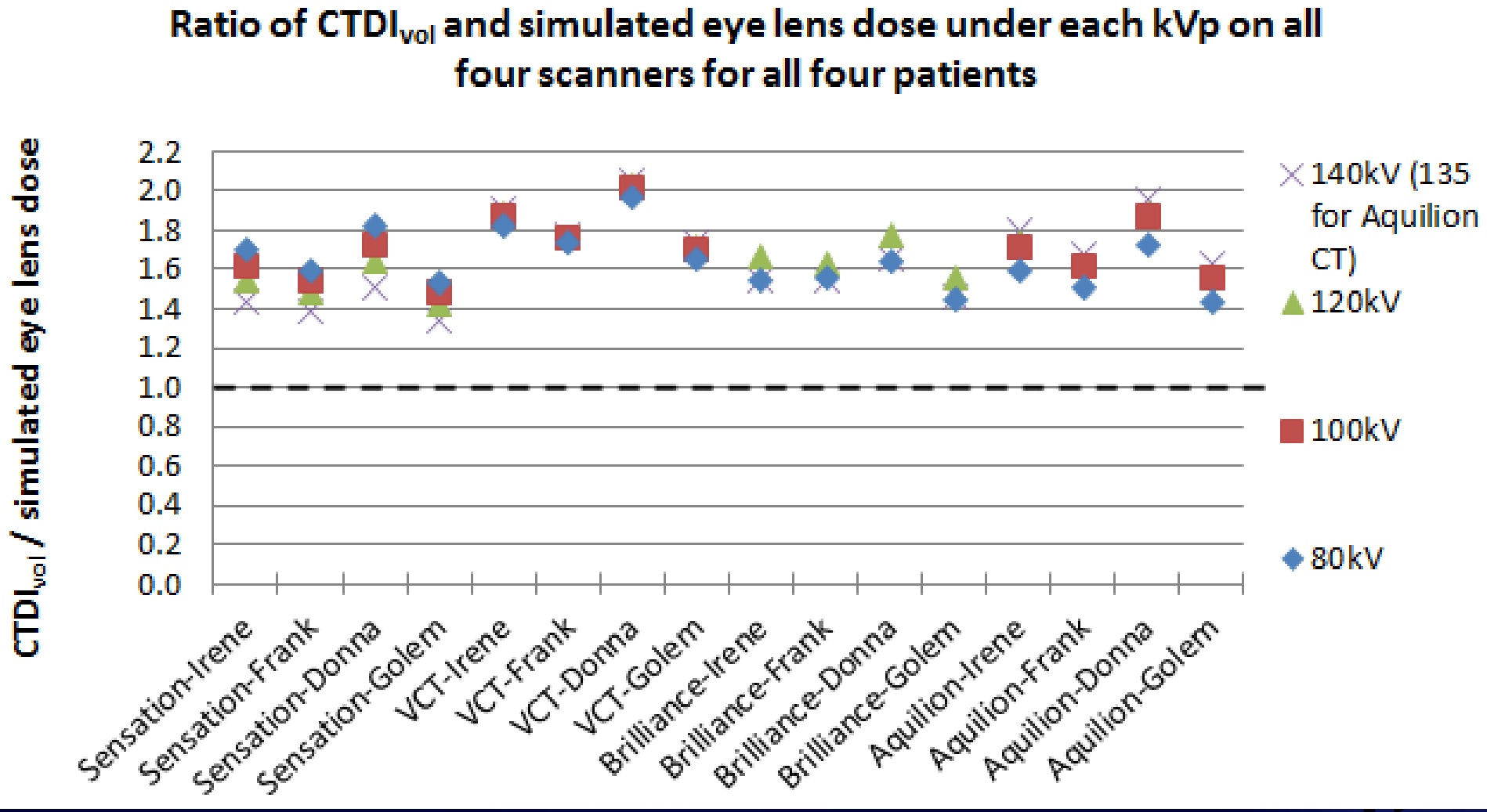
CT dose metrics

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



Bauhs, J.A., Vrieze, T.J., Primak, A.N., Bruesewitz, M.R. & McCollough, C.H. CT dosimetry: comparison of measurement techniques and devices. *Radiographics* **28**, 245-253 (2008).

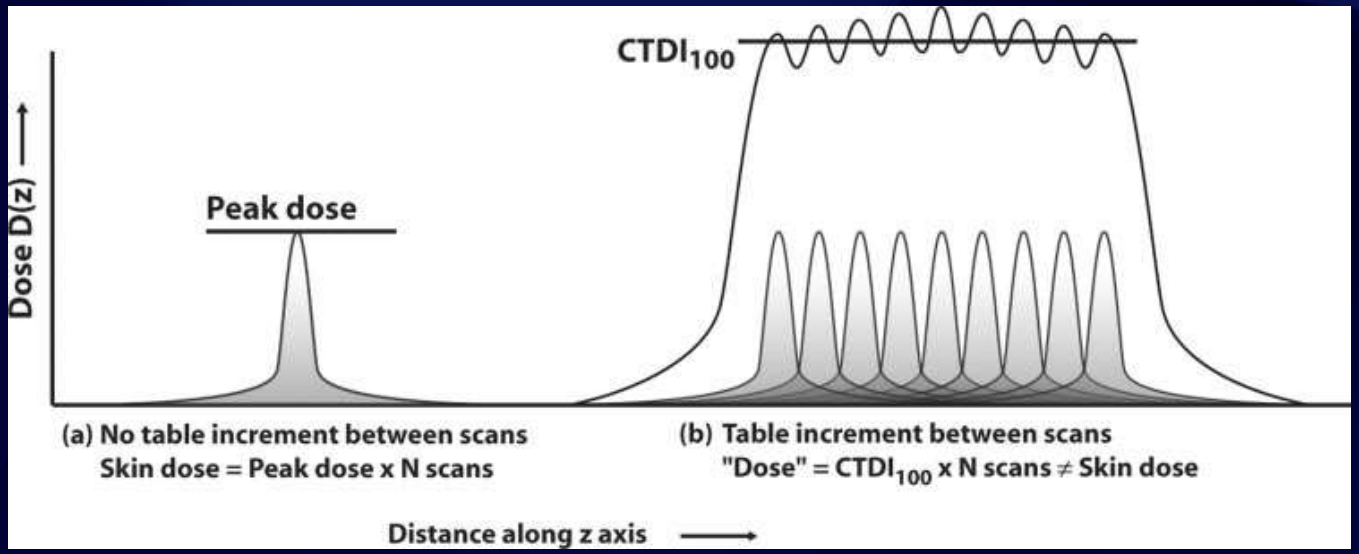
$CTDI_{vol}$ normalized by true eye lens dose



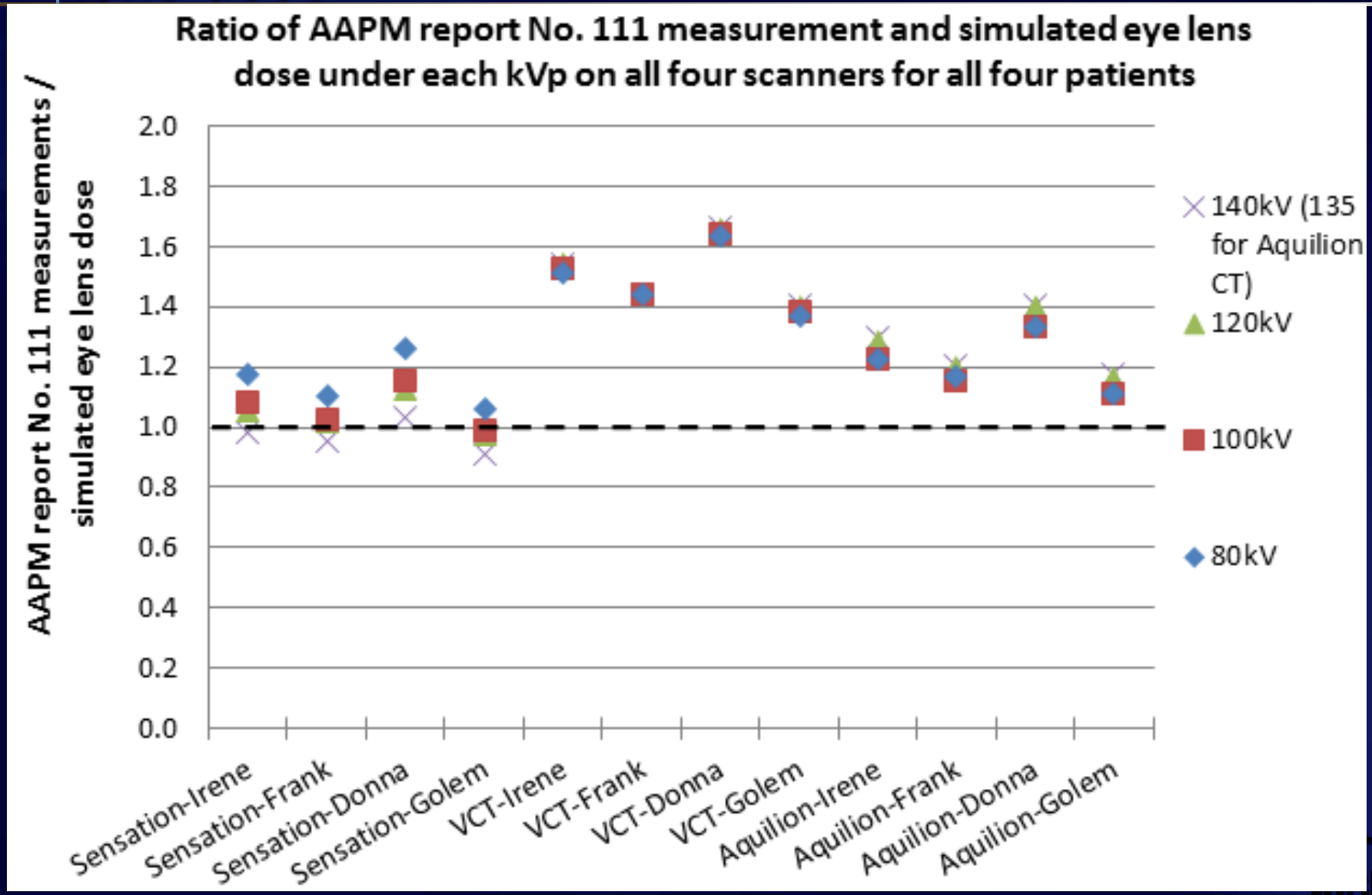
Di Zhang, et al, Med Phys, 40 (9), 2013

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



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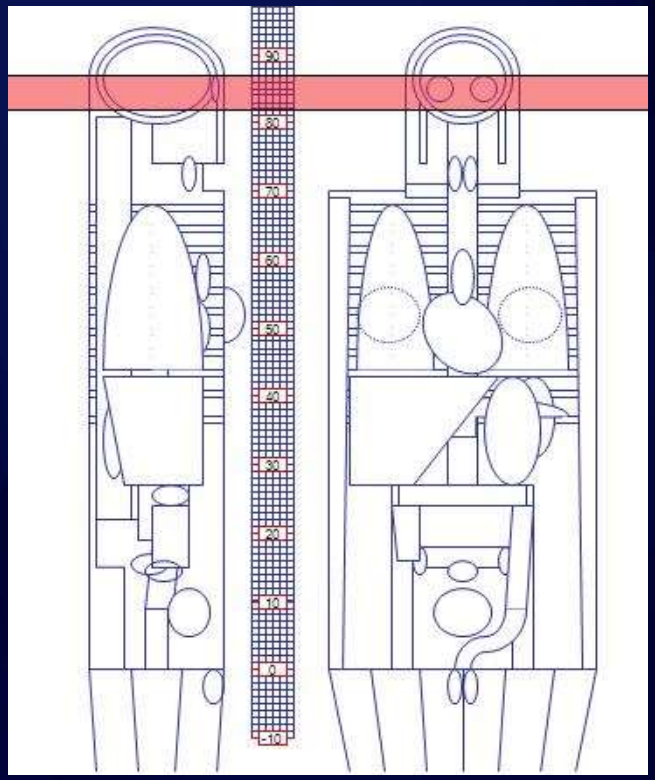
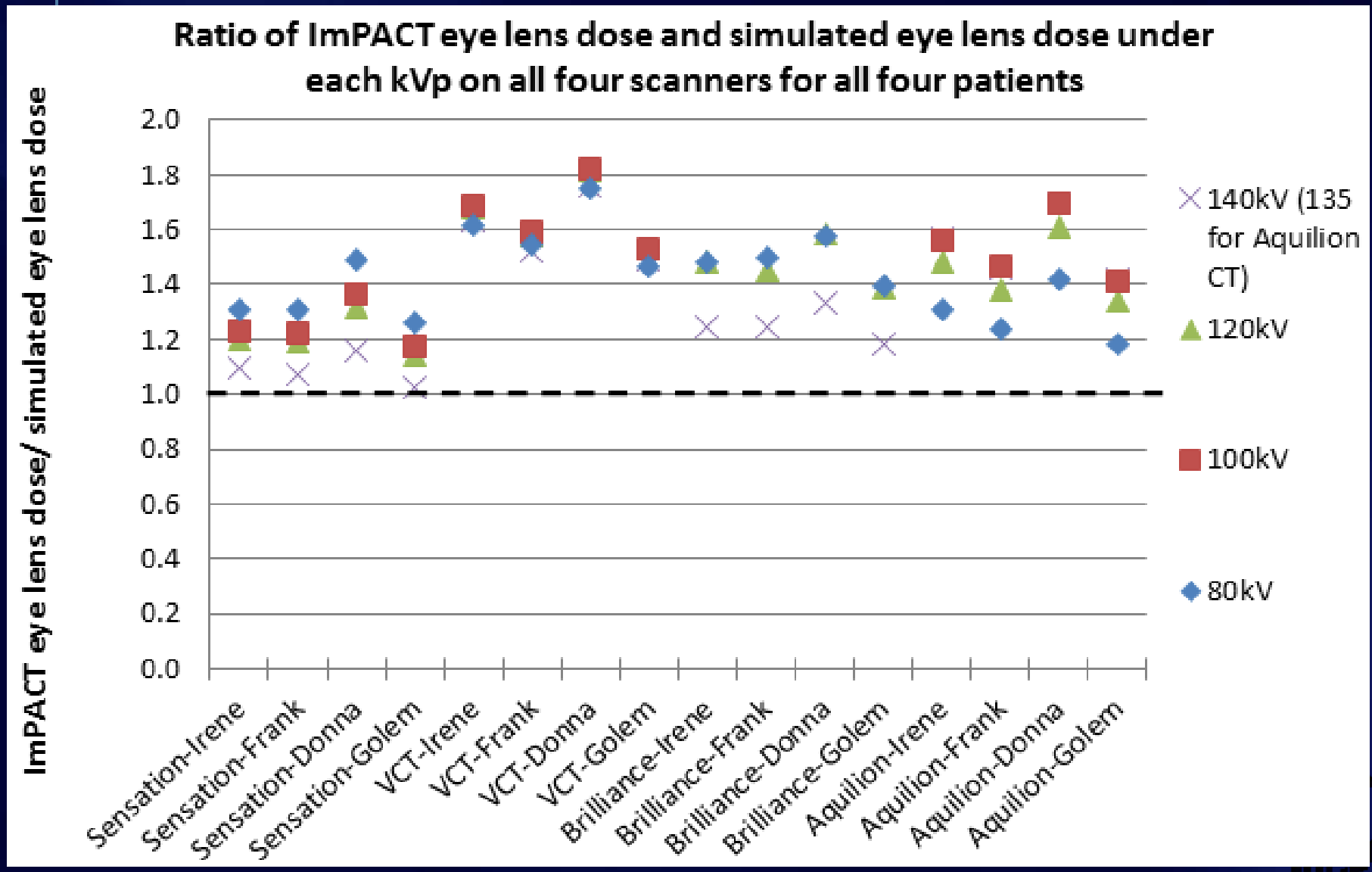
CT dose metrics

- ImPACT CT organ dose estimation tool (including eye lens)
- Modern scanner are approximated
- MIRD mathematical patient model



ImPACT estimate normalized by true eye lens dose



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

Summary of dose metrics

- $CTDI_{vol}$ overestimates eye lens dose by 30%-100%
- ImPACT overestimates by up to 80%
- TG111 measurement is a closer estimate

Outline

- Accurately estimate peak skin and eye lens dose from neuro-perfusion examinations
- Evaluate the prediction of skin and eye lens dose from dosimetry measurements
- Explore dose reduction strategies

Explore dose reduction strategies

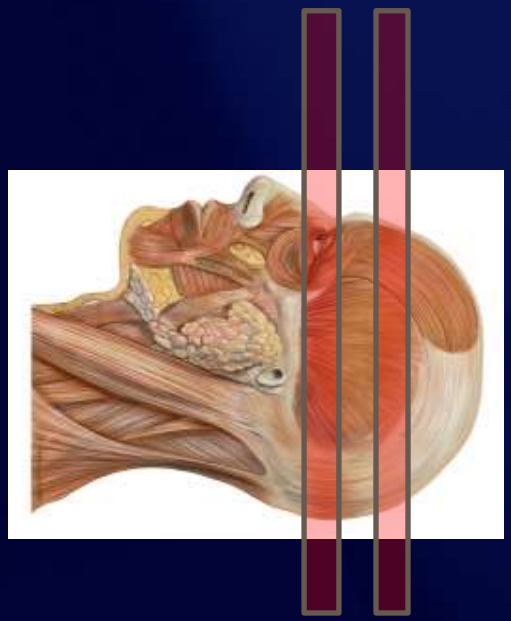
- Lowering kVp or mAs, IR (universal methods)
- Bismuth shielding, organ based tube current modulation

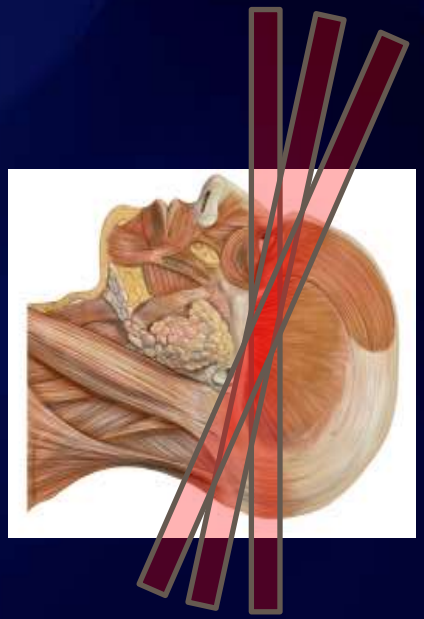
J Wang, et al, Radiology, 262(1):191-8, 2012.

  - Bismuth shielding = simply reducing tube current

Explore dose reduction strategies

- Simply based on geometry
  - Scan location
  - Gantry tilt
- The scatter component?

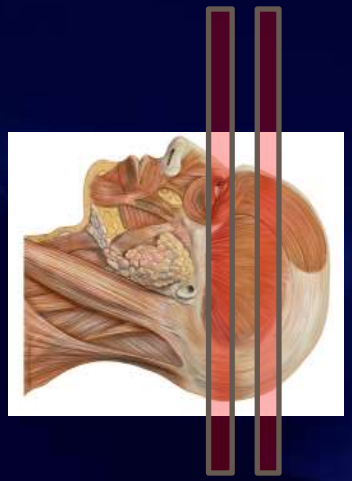




Explore dose reduction strategies

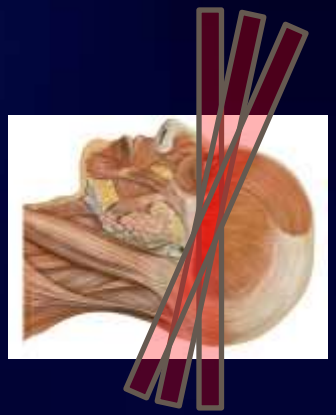
- Move scan location away

  scan location every 0.5 cm .



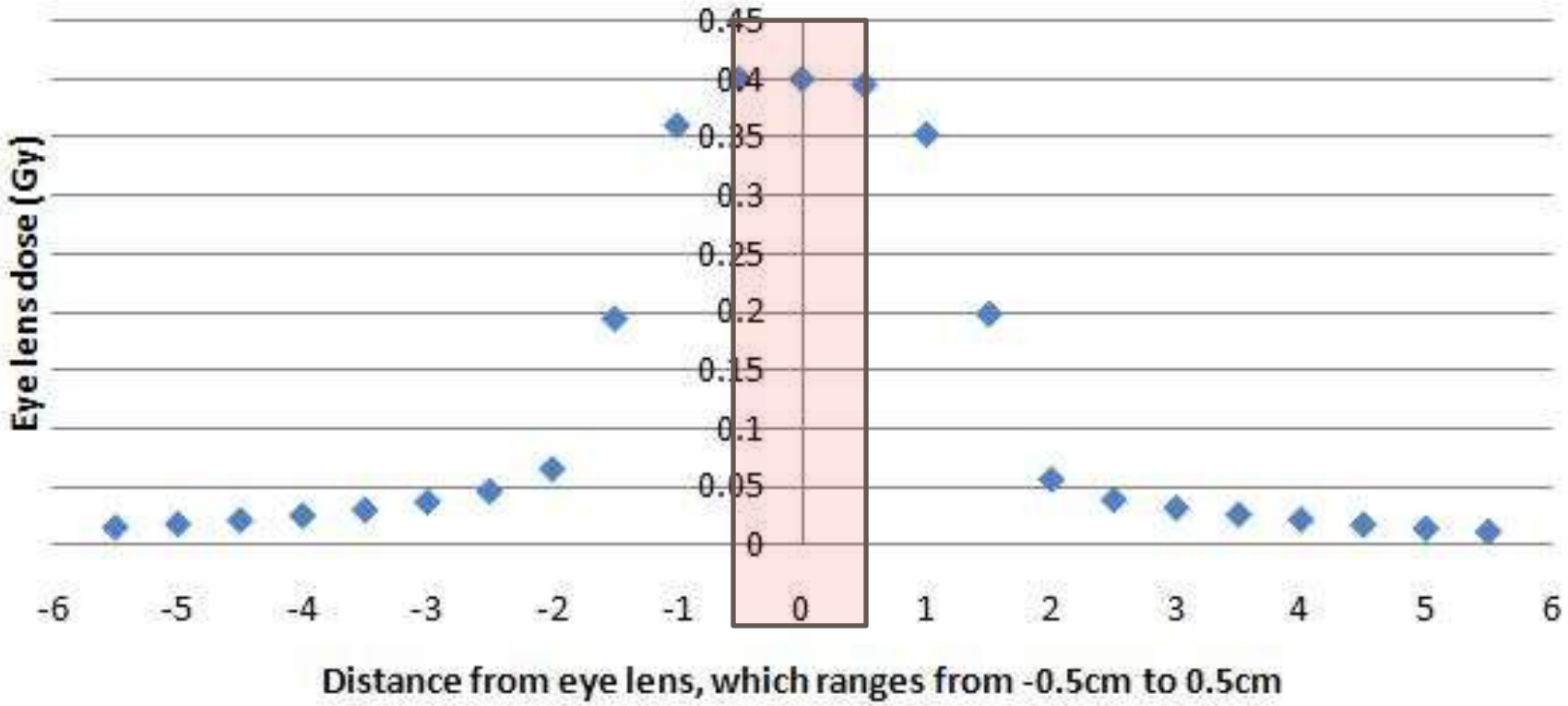
- Tilt gantry

  every 5 degree.



Dose reduction strategies

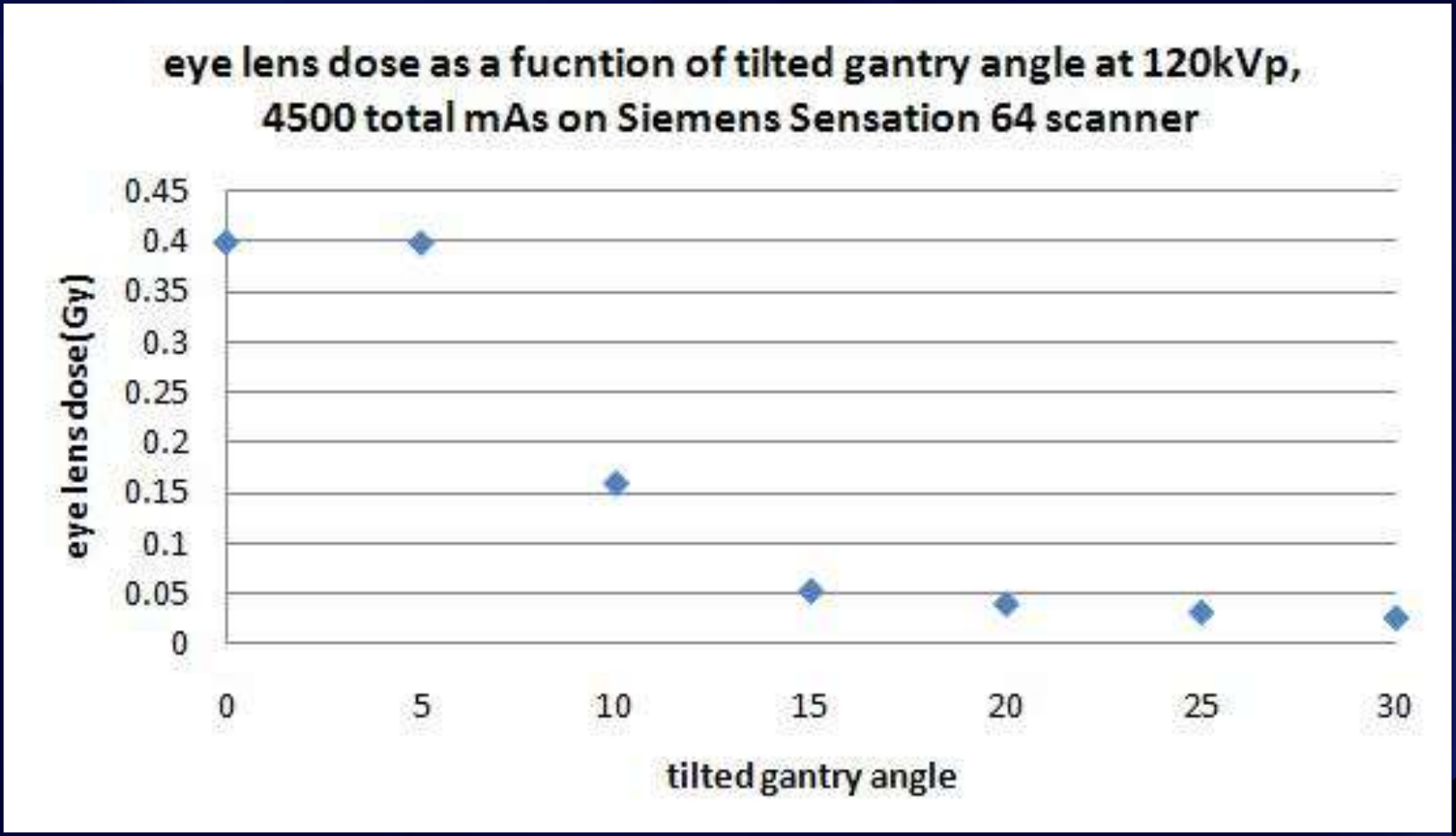
- Moving scan location away (half beam width 1.6 cm)



Di Zhang, et al, AJR, 198:412-417, 2012

Dose reduction strategies

- Tilting gantry angle



Di Zhang, et al, AJR, 198:412-417, 2012

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 and ImPACT overestimates doseTG111 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: (10%~15%)
  - Tilting the gantry angle: (10%~15%)

Thank you!