Optimization of CT Simulation Imaging

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Optimization of CT imaging

Goal: Achieve image quality that allows to perform the task at hand (diagnostic task), at the lowest possible dose

- Amount of image noise that is tolerable depends on procedure that is being performed

Example: Placement of a brachytherapy applicator

- Current workflow:
  - Many images are being acquired during applicator placement
- Dose reduction strategies:
  - Use low mAs for repeat imaging during procedure, where noise can be tolerated
  - Restrict the scan region to volume-of-interest
- Good overall image quality in final image only

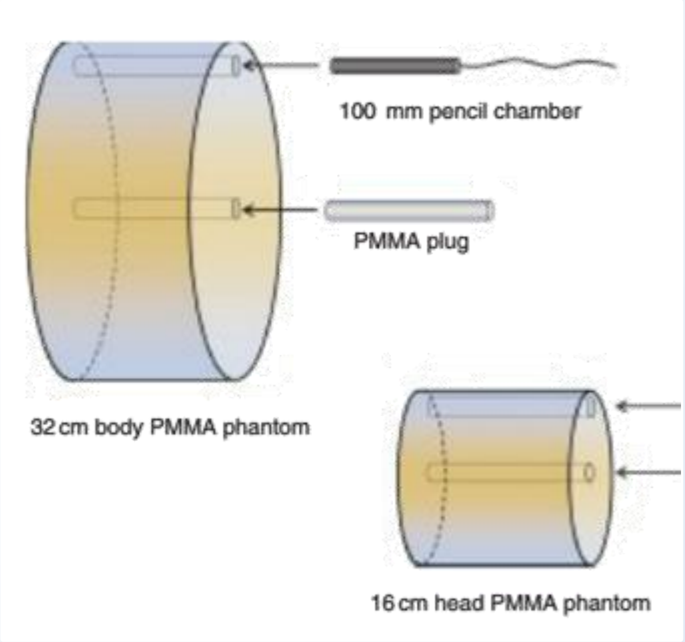
Keeping track of CT Dose: $CTDI_{vol}$

- $CTDI_{vol}$: Computed tomography dose index
  - Represents the dose to a 14.5 cm tall PMMA cylinder during a CT scan
  - Includes dose from scatter tails in MDCT
  - $CTDI_{vol}$ varies with mAs, kVp and accounts for helical pitch
  - 32cm diameter phantom for body protocols
  - 16cm diameter phantom for head/pediatric protocols

CT dose measurement

A 100mm pencil ion chamber is used to measure the integrated dose profile D(z) along the scanner axis :

$$CTDI_{100} = \frac{1}{nT} \int_{L=-50mm}^{+50mm} D(z)dz$$



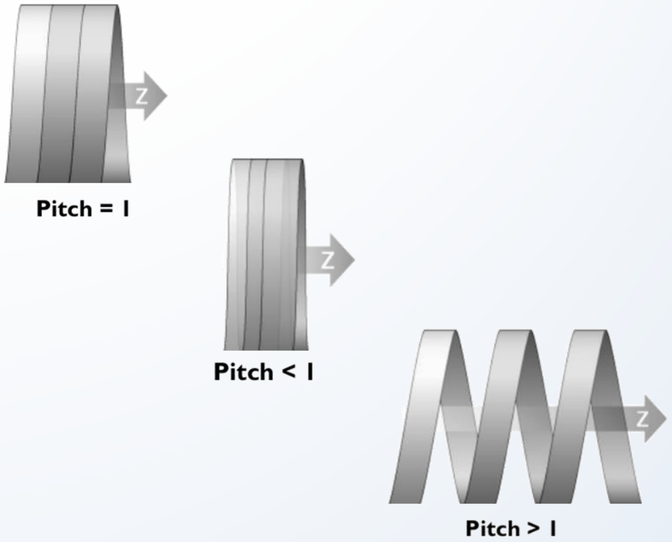
The dose to the phantom, $CTDI_w$, is estimated by weighting $CTDI_{100}$ in the center and periphery of the phantom:

$$CTDI_w = \frac{1}{3} CTDI_{100,center} + \frac{2}{3} CTDI_{100,periph}$$

Bushberg, 2012

CT dose index: $CTDI_{vol}$

- In a helical scan, the table is translated while the gantry rotates
  - pitch = 1: Table increment/rotation equal to x-ray beam width
  - pitch < 1: Overlapping scans
  - pitch > 1: Gaps in scan (artifacts)



- $CTDI_{vol}$ is the volume-weighted dose index that accounts for pitch:

$$CTDI_{vol} = \frac{CTDI_w}{pitch}$$

Where to find guidance

- Use diagnostic CT as a guideline:
  - The AAPM has published CT protocols

    http://www.aapm.org/pubs/CTProtocols/
- Diagnostic reference levels (DRL):
  - 75th percentile of $CTDI_{vol}$ of all examinations
  - Achievable dose (AD) – 50th percentile
  - Based on multi-institution, nationwide data

DRL for $CTDI_{vol}$

Table 3
Diagnostic Reference Levels and Achievable Doses for Adult and Pediatric CT ($CTDI_{vol}$)

	Patient Lateral (LAT) Dimension	CTDI Phantom Diameter (cm)	DRL (mGy)	AD (mGy)
Adult head [6,9]	16	16	75	57
Adult abdomen-pelvis [6,9]	38	32	25	17
Adult Chest [6]	35	32	21	14
Pediatric 5 year old head [6]	15	16	40	31
Pediatric 5 year old abdomen-pelvis [9]	20	16	20	14

ACR–AAPM practice parameter for diagnostic reference levels and achievable doses in medical x-ray imaging (2014)

Dose-length product

- $CTDI_{vol}$ by itself is independent of the scan volume
  - No information on dose to patient
- Dose-length product (DLP) incorporates scan length L:

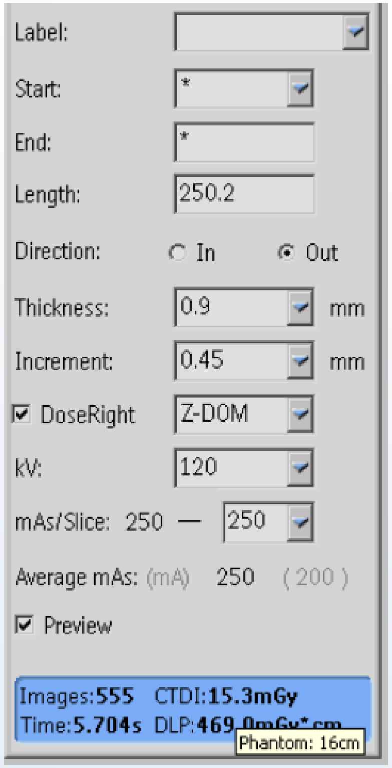
$$DLP = L * CTDI_{vol}$$

Effective dose can be estimated from DLP:

Multisection CT protocols: Sex- and age-specific conversion factors to determine effective dose from dose-length product. P Deak, Y Smal, W Kalender. *Radiology, 257 (2010)*

I'm ready to scan my patient. How can I know $CTDI_{vol}$ and DLP?

- CTDIvol and DLP are displayed on the scanner console prior to performing a scan!

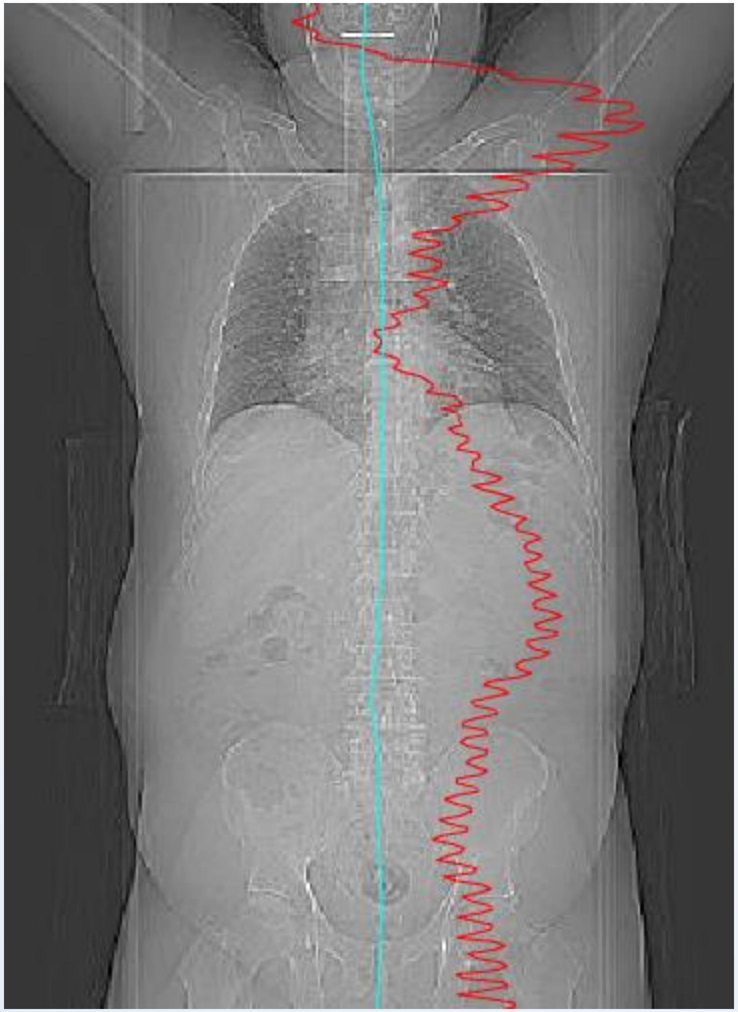


The pre-scan $CTDI_{vol}$ or DLP is high. What can I do to reduce it?

Adjusting these parameters can reduce CTDIvol:

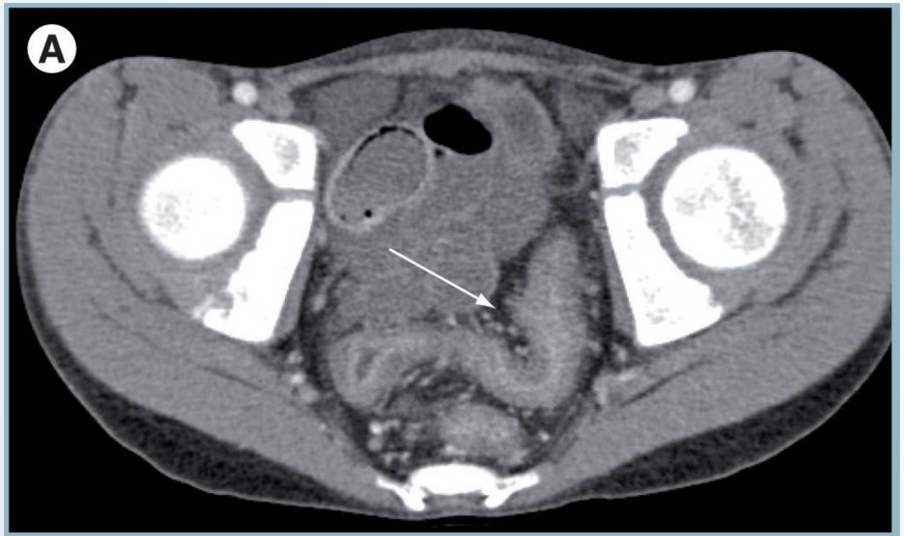
- mAs
- Pitch
- kVp
- X-ray beam collimation
  - Does not affect displayed CTDIvol, but affects dose efficiency
- Tube current modulation
  - Does not directly affect displayed $CTDI_{vol}$, but will reduce dose in less attenuating anatomical regions, such as thorax

Tube current modulation

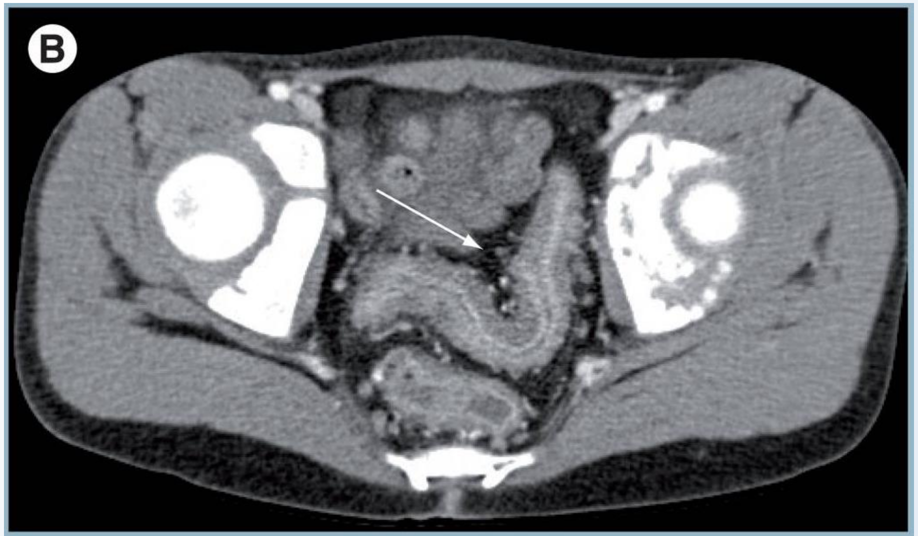


Tube mA varies to compensate for changes of attenuation in different anatomic regions

Effect of kVp on $CTDI_{vol}$



120 kV, $CTDI_{vol}$ = 5.18 mGy



100 kV, $CTDI_{vol}$ = 3.98 mGy

From: L. Yu et al, Radiation dose reduction in computed tomography: techniques and future perspective. Imaging Med. 2009 Oct; 1(1): 65–84.

Parameter	Effect on Dose
mAs	Reducing mAs reduces dose mAs proportional to $CTDI_{vol}$!
Pitch	Increasing pitch reduces dose
kVp	Lowering kVp will reduce $CTDI_{vol}$. Relationship is not linear.
Collimation	Use widest possible collimation
Scan range	Restrict the scan range to the region of interest. Reduces DLP, no effect on $CTDI_{vol}$. Particularly important for repeat scans.
Dose modulation	Aims to maintain same noise level In combination scans (Chest/Abd)

Which statement is FALSE? $CTDI_{vol}$ is ...

20%	1. proportional to mAs
20%	2. patient dose
20%	3. represents the scanner output
20%	4. inverse proportional to pitch
20%	5. based on a reference phantom

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Correct Answer:

2: $CTDI_{vol}$ is **NOT** patient dose

Reference:

- Cynthia H. McCollough, CT dose: how to measure, how to reduce. Health Physics **95**, (2008) 508–517.

My planning CT image does not show the same anatomic detail as the diagnostic CT. How can I improve it?

CT reconstruction parameters

There are many reconstruction parameters that strongly affect the CT image appearance. These parameters need to be chosen according to anatomic structures to be visualized.

There may be differences in how the scans are performed that will affect image quality, such as breath hold or free breathing, or administration of contrast agent.

Review: CT reconstruction parameters

- Reconstruction field-of-view/matrix size
  - In planning scans, the FOV is larger because it includes more anatomy such as elbows
  - The matrix size on a scanner tends to be fixed to 512x512, which can produce large pixel sizes to cover large area
  - To increase resolution, increase matrix size or decrease FOV
- Reconstruction filter
  - Standard B: CT # most accurate, high-resolution detail may be blurred
  - Y-Sharp: Better high-frequency detail
- Slice thickness, spacing
  - Thick slices are less noisy
  - Slice spacing as close as needed

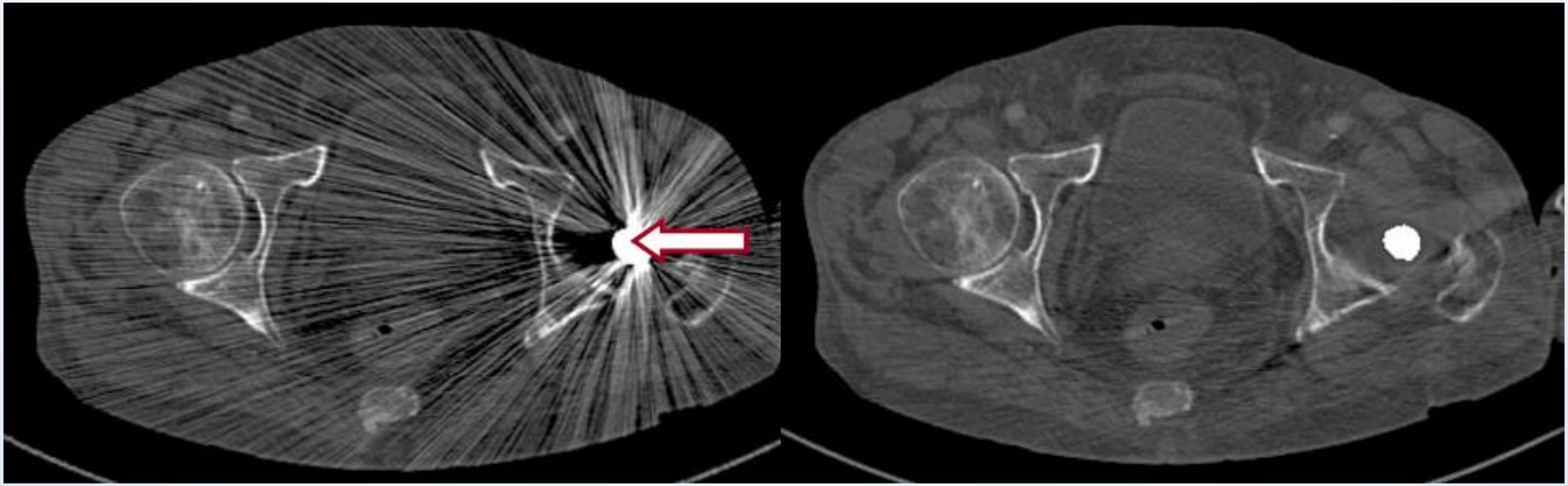
Review: CT reconstruction parameters

- Multiple reconstructions from one CT acquisition
  - Re-reconstruct with different parameter settings to improve anatomic detail
- Display window settings
  - Different window width/level settings portray different types of anatomy (lung window vs. soft-tissue or bone window)
- Iterative reconstruction (if available on system)
  - Can reduce noise in high-contrast object, such as lung tumors

Advanced image reconstruction tools: Metal artifact reduction (MAR)

Available on CT scanners as optional feature

- Improvement of anatomic visibility
- Better CT # accuracy

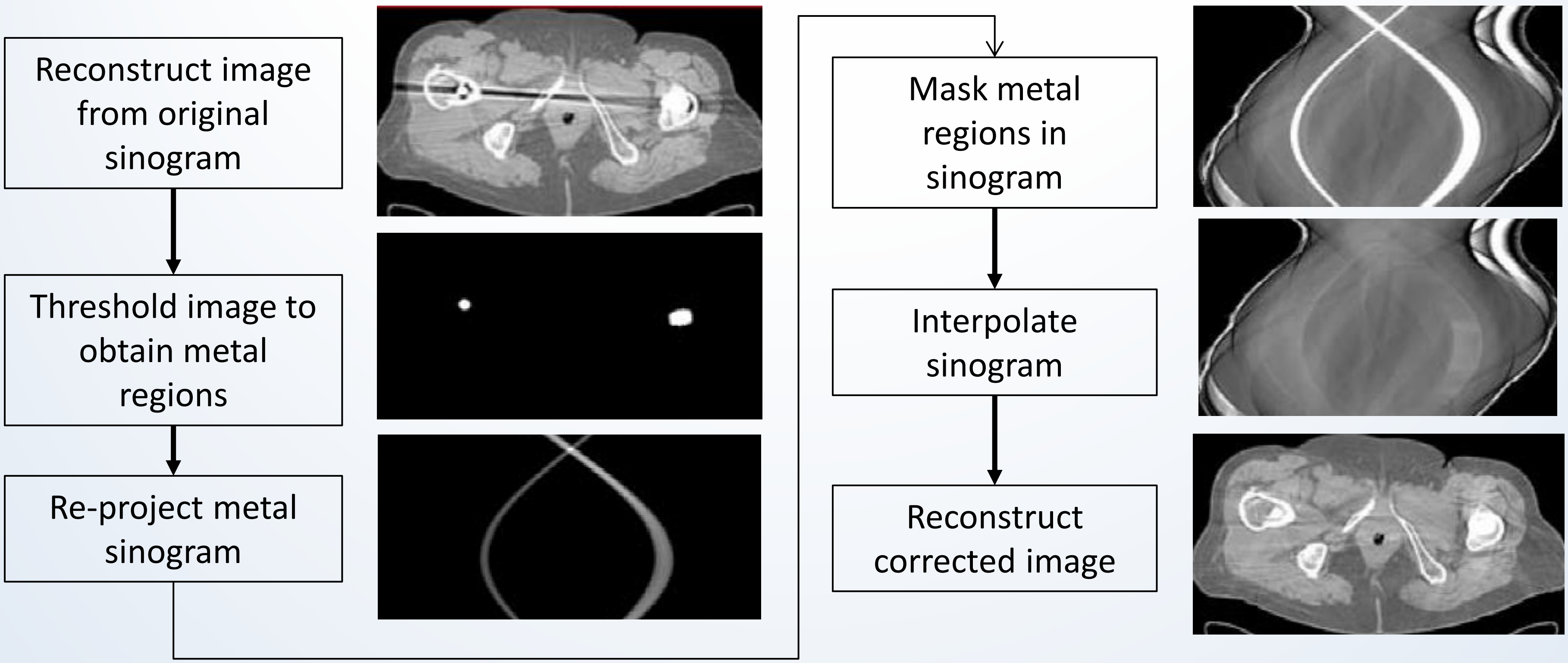


Meyer E et al., Normalized metal artifact reduction (NMAR) in computed tomography, Medical Physics, 37, 5482-5493 (2010)

General principle:

1. Identify metal regions

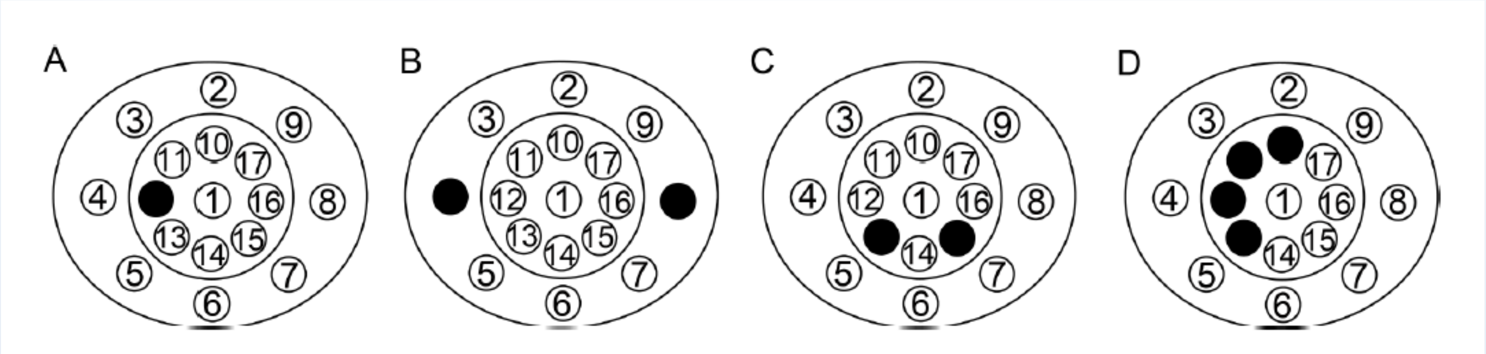
2. Correct sinogram



E. Meyer, R. Raupach, M. Lell, B. Schmidt, M. Kachelrieß. Normalized metal artifact reduction (NMAR) in computed tomography. Med. Phys. **37**, 5482 (2010).

Evaluation of an iterative MAR-algorithm

- The complexity of the metal structures affects the effectiveness of MAR.
- Use test phantom with different metal arrangements:



From: Axente M, et al., Clinical evaluation of the iterative metal artifact reduction algorithm for CT simulation in radiotherapy. Medical Physics, 42, 1170-1183 (2015)

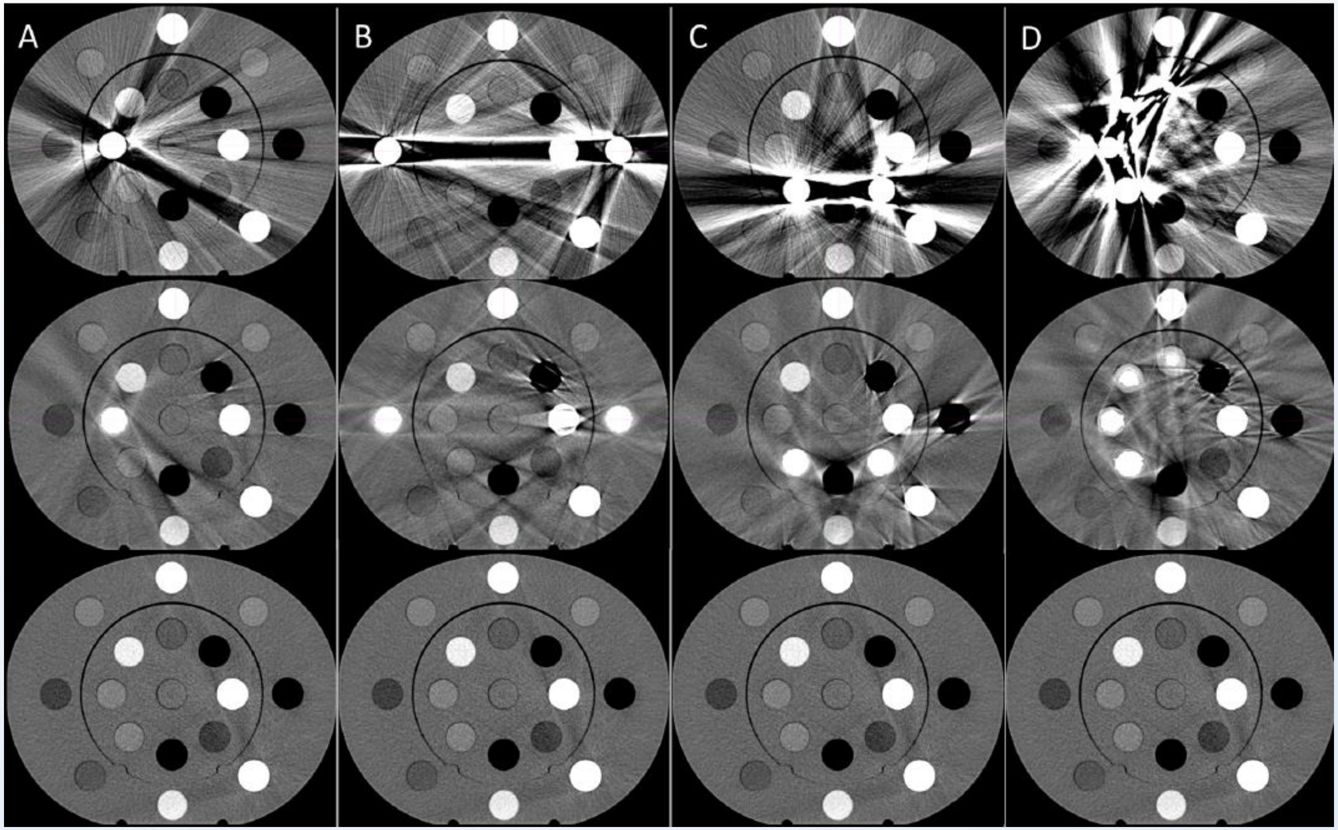
CT number accuracy with MAR

Evaluation of a prototype algorithm using a phantom with 25mm steel inserts:

W/o MAR

With MAR

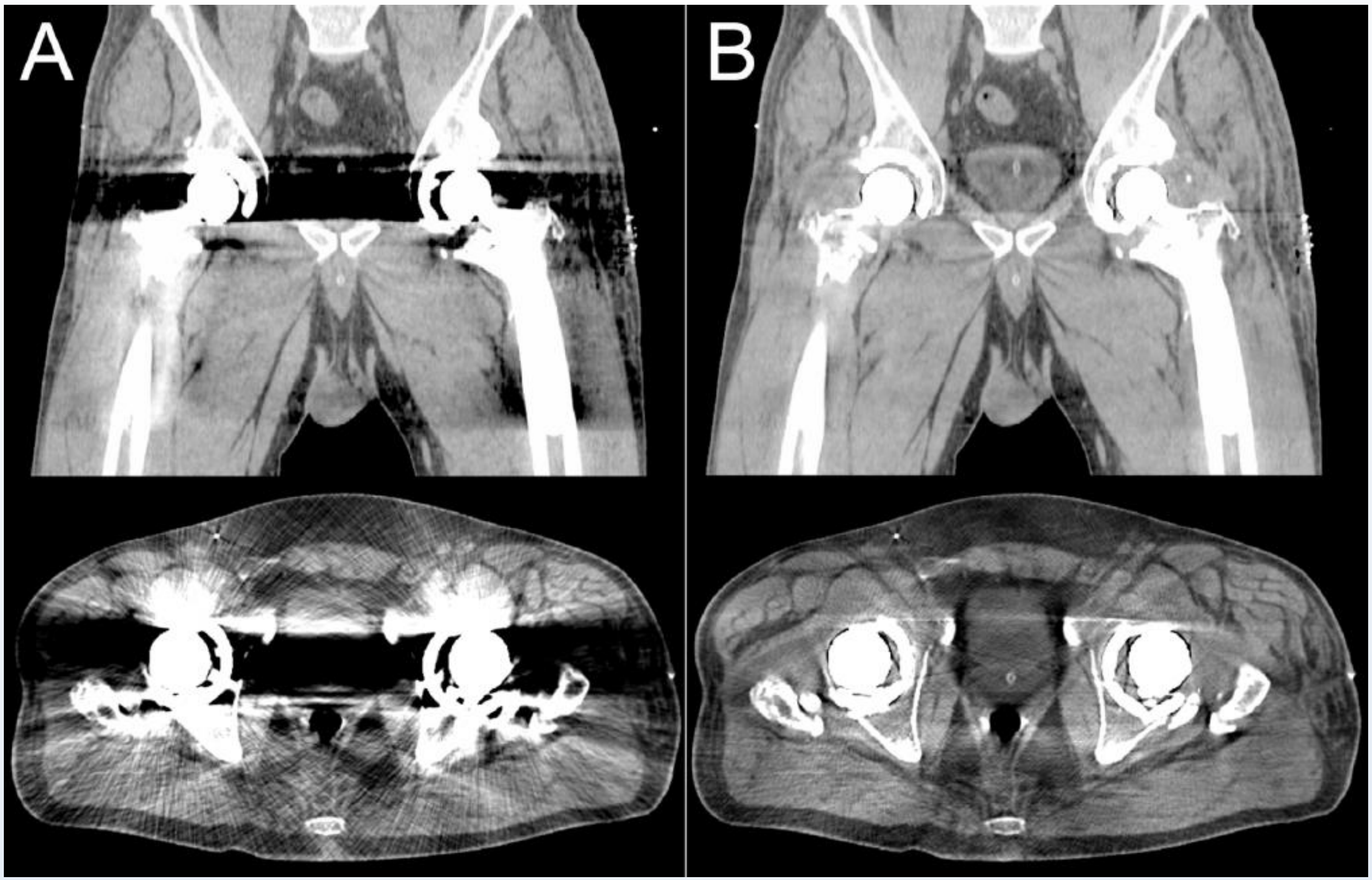
Phantom w/o metal



From: Axente M, et al., Clinical evaluation of the iterative metal artifact reduction algorithm for CT simulation in radiotherapy. Medical Physics, 42, 1170-1183 (2015)

Patient with hip implants

w/o MAR with MAR



From: Axente M, et al., Clinical evaluation of the iterative metal artifact reduction algorithm for CT simulation in radiotherapy. Medical Physics, 42, 1170-1183 (2015)

In which situation is metal artifact reduction (MAR) expected to be the least effective?

20%	1.	CT with hip prosthesis
20%	2.	CT # accuracy
20%	3.	CT with LDR Fletcher-Suit applicator
20%	4.	CT with spinal fixation rods
20%	5.	CT with dental filling artifacts

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Correct Answer:

5: CT with dental filling artifacts.

Close arrangements of several metal objects is most difficult to correct for.

Reference:

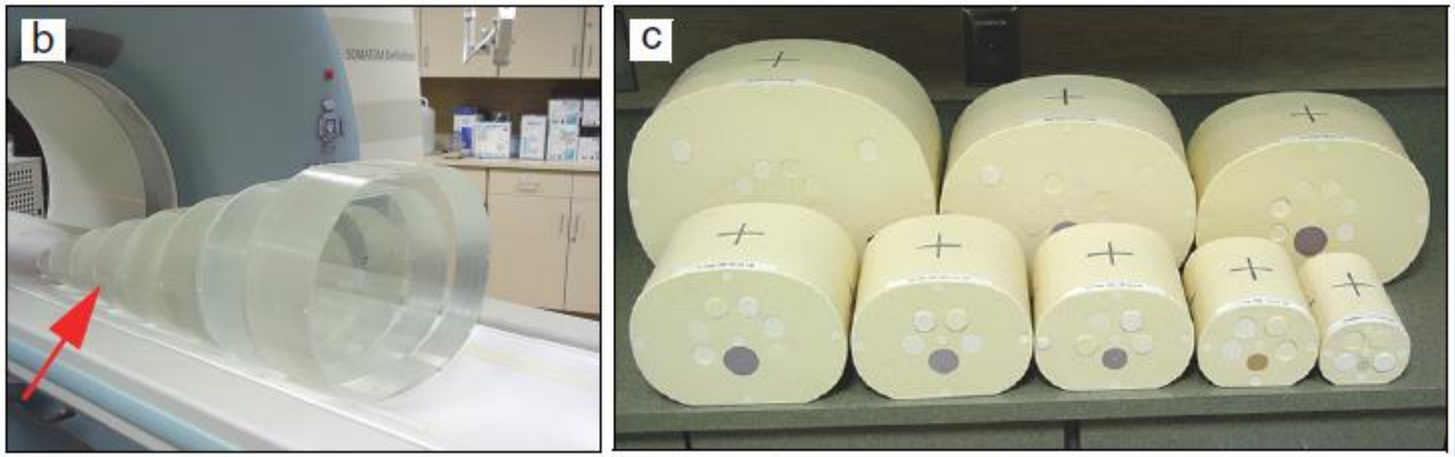
- Jessie Y Huang, et al, “An evaluation of three commercially available metal artifact reduction methods for CT imaging”, Phys. Med. Biol. **60** (2015), 1047-1067.

Pediatric patients

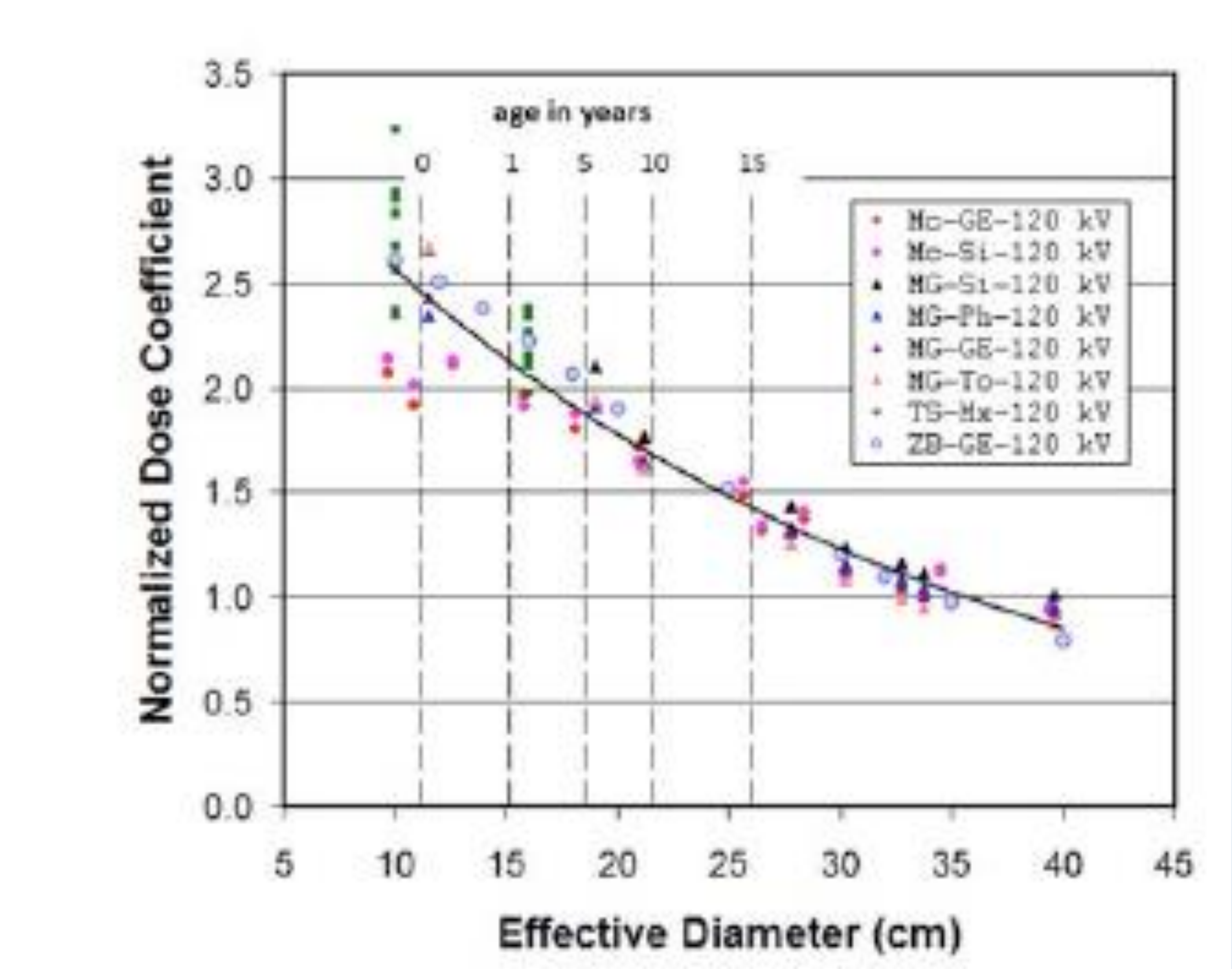
- Image gently: "child-size" radiation
  - Children are more sensitive to radiation and have a longer lifetime during which cancer may develop
  - Instructions for child-sizing CT protocols on image gently website http://www.imagegently.org/Portals/6/Procedures/IG%20CT%20Protocols%20111714.pdf

Size-specific dose estimate (SSDE)

- SSDE is an estimate of the absorbed dose to a uniform phantom
- Dose conversion coefficients allow to infer size-specific doses for a given CTDIvol

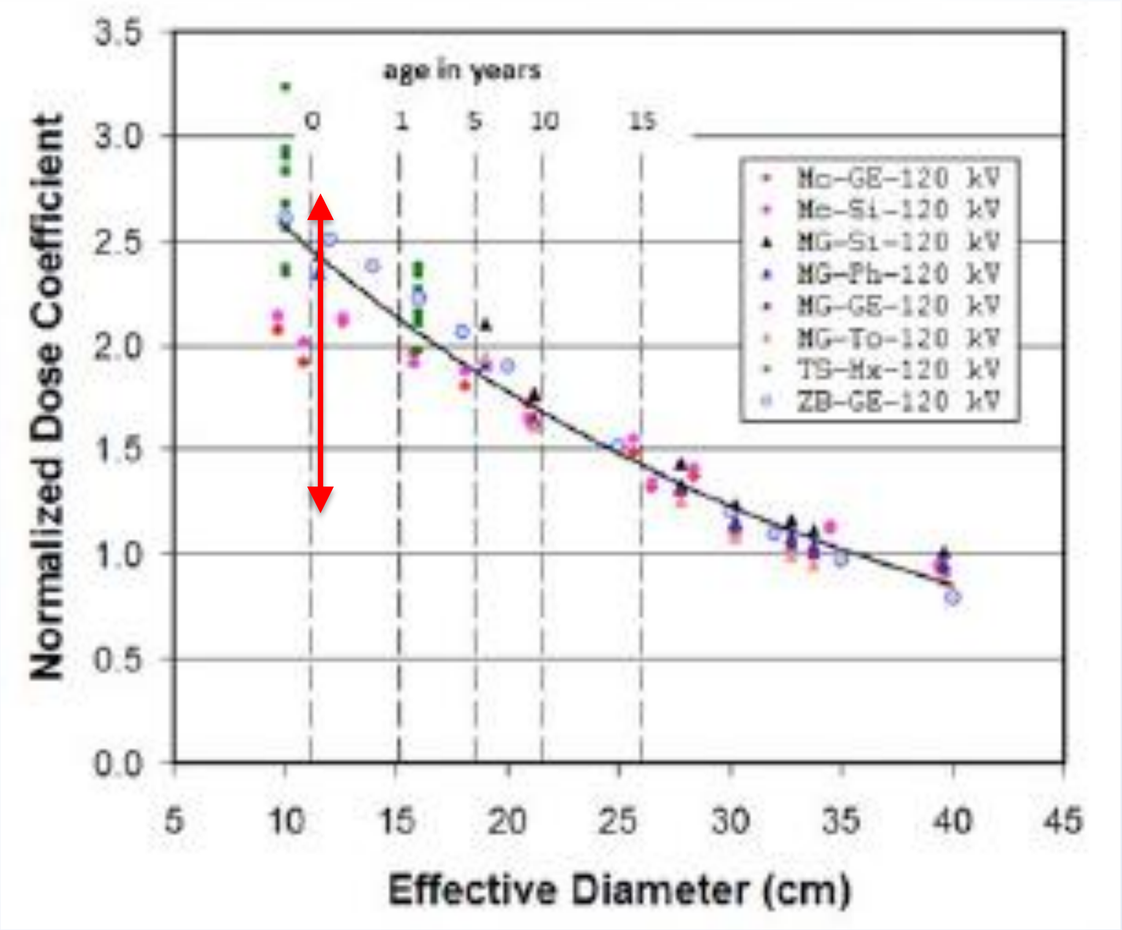


Normalized Dose Coefficients for the 32cm CTDI phantom



How to child-size protocols

For the same acquisition parameters, the dose to a newborn is much higher than that to an adult



-> Reduce mAs so as to match SSDE

How to child-size protocols

Image gently: Match SSDE for pediatric patients with that for adults

Age	Effective Diameter (cm)	f = $SSDE/CTDI_{vol}$ conv. factor	mAs reduction factor f_{adult}/f_{child}	SSDE (mGy)
newborn	12	2.38	0.52	23
1yr	14	2.22	0.55	23
5yr	17	1.98	0.62	23
10yr	20	1.53	0.7	23
ADULT	30	1.23	1	23

Child-sizing protocols

Image gently suggests more aggressive dose reduction for younger patients:

Age	Effective Diameter (cm)	$CTDI_{vol}$ to SSDE conversion factor	mAs reduction factor		
			Limited (matching SSDE)	Moderate	Aggressive
newborn	12	2.38	0.52	0.39	0.25
1yr	14	2.22	0.55	0.42	0.29
5yr	17	1.98	0.62	0.50	0.39
10yr	20	1.53	0.7	0.62	0.53
ADULT	30	1.23	1	1	1

Child-sizing protocols: example

Download CT protocols (excel) from image gently website, http://www.imagegently.org/Portals/6/IG%20CT%20PPT%20Tables%20Web%20Version%20(12-16-14).xls

Table I: mAs Reduction Factors for the Pediatric Body

Abdomen/	Abdomen/	Abdomen/	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE					
Pelvis:	Pelvis:	Pelvis:	120	200	1	1.0	1.0	23					
AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor	*Limited* mAs SSDE (mGy)	*Moderate* mAs SSDE (mGy)	*Aggres-sive* mAs SSDE (mGy)	*Limited* NB = Adult SSDE Estimated mAs	*Moderate* NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs
10	14	11.8	4	newborn	0.52	0.39	0.25	23	17	11	104	77	50
11	16	13.3	10	1 yr	0.55	0.42	0.29	23	18	12	110	84	59
14	20	16.7	18	5 yr	0.62	0.50	0.39	23	19	15	123	100	78
16	25	20.0	33	10 yr	0.70	0.62	0.53	23	20	18	140	123	106
19	29	23.5	54	15 yr	0.80	0.74	0.68	23	21	20	160	148	137
22	32	26.5	65	20 yr	0.89	0.86	0.83	23	22	22	179	172	165
25	35	29.6	75	md adult	1.00	1.00	1.00	23	23	23	200	200	200
31	41	35.7	110	lg adult	1.21	1.28	1.35	23	25	27	242	256	270

Child-sizing ..

From your adult protocol, find mA, rotation time, pitch and enter into spread sheet:

Table I: mAs Reduction Factors for the Pediatric Body

Abdomen/ Pelvis:	Abdomen/ Pelvis:	Abdomen/ Pelvis:	kVp	mA	Time (sec)	Pitch During Measured CTDIvol	Pitch During Clinical Exam	Adult SSDE
			120	200	1	1.0	1.0	23

AP Thickness (cm)	LAT Thickness (cm)	Effective Diameter (cm)	Mass (kg)	Age	*Limited* mAs Reduction Factor	*Moderate* mAs Reduction Factor	*Aggressive* mAs Reduction Factor	*Limited* mAs SSDE (mGy)	*Moderate* mAs SSDE (mGy)	*Aggres-sive* mAs SSDE (mGy)	*Limited* NB = Adult SSDE Estimated mAs	*Moderate* NB = 0.75 * Adult SSDE Estimated mAs	*Aggressive* NB = 0.5 * Adult SSDE Estimated mAs
10	14	11.8	4	newborn	0.52	0.39	0.25	23	17	11	104	77	50
11	16	13.3	10	1 yr	0.55	0.42	0.29	23	18	12	110	84	59
14	20	16.7	18	5 yr	0.62	0.50	0.39	23	19	15	123	100	78
16	25	20.0	33	10 yr	0.70	0.62	0.53	23	20	18	140	123	106
19	29	23.5	54	15 yr	0.80	0.74	0.68	23	21	20	160	148	137
22	32	26.5	65	20 yr	0.89	0.86	0.83	23	22	22	179	172	165
25	35	29.6	75	md adult	1.00	1.00	1.00	23	23	23	200	200	200
31	41	35.7	110	lg adult	1.21	1.28	1.35	23	25	27	242	256	270

weight (age) specific mAs:

Worksheet is locked, only yellow fields can be modified.

For a given CTDIvol, how different is the SSDE in newborns compared to SSDE for adults?

20%	1. They are equal
20%	2. about 4x greater
20%	3. about 4x lower
20%	4. about 2x greater
20%	5. about 2x lower

10

Correct Answer:

4: about 2x greater.

The size-specific dose estimate for newborns is about twice that for an adult, for the same $CTDI_{vol}$.

Reference:

- AAPM report 204


Thank You!