Dual-Energy CT: The Many Technologies and Implementations and What They Mean for Physicists

Danielle Beaulieu, M.Sc.
Department of Radiology
Boston Children's Hospital

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Learning Objectives

1. Dual-Energy CT Review
2. Dual-Energy Technologies
3. Annual Testing
   A. Image Quality
   B. Dosimetry

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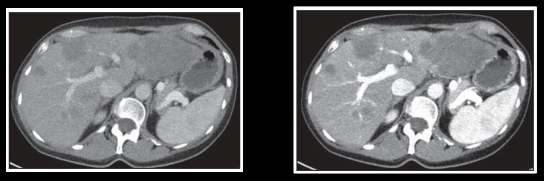
Dual-Energy CT Review

Two kVps, one projection per kVp



100 kVp 140 kVp

Images from [1].

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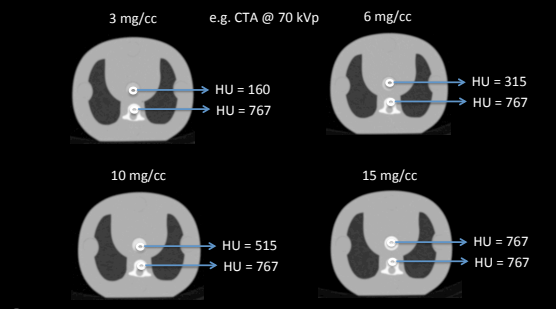
Dual-Energy CT Review



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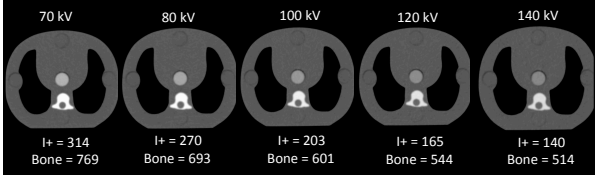
Dual-Energy CT Review



70 kV	80 kV	100 kV	120 kV	140 kV
I+ = 314 Bone = 769	I+ = 270 Bone = 693	I+ = 203 Bone = 601	I+ = 165 Bone = 544	I+ = 140 Bone = 514

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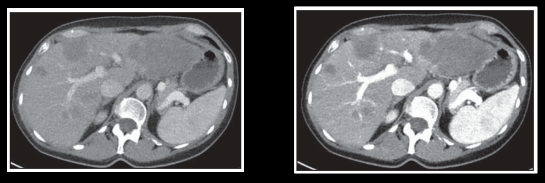
Dual-Energy CT Review



100 kVp

140 kVp

Images from [1].

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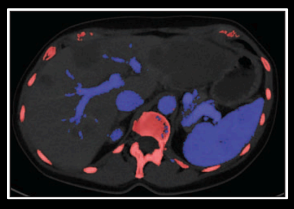
Dual-Energy CT Review



Iodine (Z = 53)
Xenon (Z = 54)
Barium (Z = 56)

Calcium (Z = 20)

Photoelectric effect
Peaks at Z = 55.

Calcium highlighted in red, iodine highlighted in blue

Image from [1].

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Dual-Energy CT Review

The mixed image I from two images I_L and I_H

$$I = I_L w_L + I_H w_H$$

weighting factors w_L and w_H, where $w_L + w_H = 1$.

One more factor to consider for optimization.

Formula from [2].

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Vendor Technologies

- Single-source, single-energy (Philips)
  - kV filtering via layered detectors
- Single-source, dual-energy (GE)
  - Rapid kV switching
- Dual-source, dual-energy (Siemens)
- Others…

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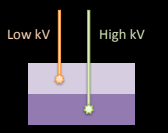
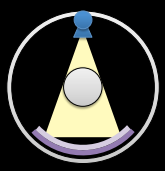
kVp Filtering ("Sandwich Detector")

Single-source, single-energy

Philips

Strengths	Weaknesses
• Simultaneous data acquisition	• Relatively high overlap of the spectra • Noise level of simultaneous projections can differ





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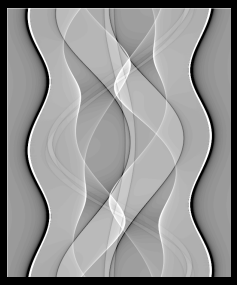
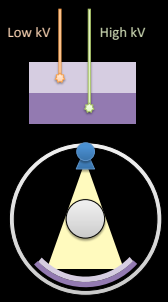
Noise Matching





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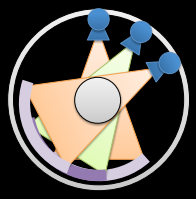
Fast kVp Switching

Single-source, dual-energy

GE

Strengths	Weaknesses
• Can adjust mAs for each projection	• Relatively high overlap of the spectra • Adjacent projections slightly offset



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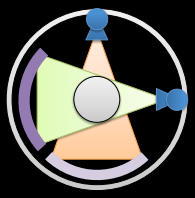
Dual-Source

Dual-source, dual-energy

Siemens

Strengths	Weaknesses
• Independent optimization of tube current and filtration • Relatively low overlap of the spectra	• 95 degree phase shift between low- and high-energy images • Scatter from one tube in the other detectors



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Siemens SOMATOM Force

Tin filter on one tube increases spectral separation between the low- and high-energy beams

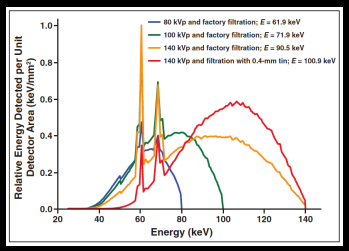

Image from [3].

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ACR Annual Testing Requirements

A. Review of Clinical Protocols
B. Scout Prescription and Alignment Light Accuracy
C. Image Thickness – Axial Mode
D. Table Travel Accuracy
E. Radiation Beam Width
F. Low-Contrast Performance
G. Spatial Resolution
H. CT Number Accuracy
I. Artifact Evaluation
J. CT Number Uniformity
K. Dosimetry
L. Gray Level Performance of CT Acquisition Display Monitors

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Image Quality

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Image Quality

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Image Quality of DE Scans

ACR Phantom Tests:

- Low-Contrast Performance
- Spatial Resolution
- CT Number Accuracy
- Artifact Evaluation
- CT Number Uniformity

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Image Quality of DE Scans

Procedure:

1. Select SE protocol
2. Record displayed $CTDI_{vol}$
3. Scan ACR phantom
4. Select DE protocol
5. Match $CTDI_{vol}$ from SE protocol
6. Scan the ACR phantom

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Image Quality of DE Scans

Adult Abdomen

Single-Energy
120 kVp

Dual-Energy
90/150Sn kVp

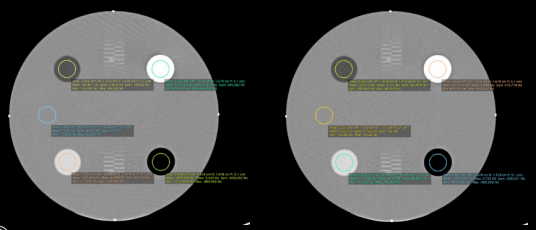

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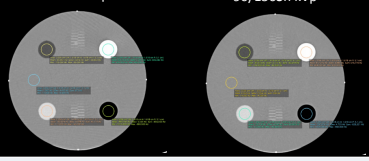
Image Quality of DE Scans

Single-Energy
120 kVp

Dual-Energy
90/150Sn kVp



Adult Abdomen (Dose Class 1)

Material	Mean (HU)		Difference (HU)	Tolerance (HU)	
	Single-Energy	Dual-Energy	|DE-SE|	Min	Max
Water	1.06	0.76	0.30	-7	7
Polyethylene	-93.96	-94.32	0.36	-107	-84
Bone	925.76	917.31	8.39	850	970
Acrilyc	130.02	128.14	1.88	110	135
Air	-995.34	-992.92	2.42	-1005	-970

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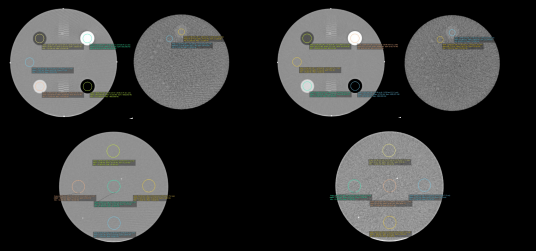
Image Quality of DE Scans

Single-Energy
120 kVp

Dual-Energy
90/150Sn kVp



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Dosimetry

ACR CT Accreditation Program Testing Instructions

Examination	Pass/Fail Criteria $CTDI_{vol}$ (mGy)	Reference Levels $CTDI_{vol}$ (mGy)
Adult Head	80	75
Adult Abdomen	30	25
Pediatric Head	40	35
Pediatric Abdomen	20	15

Joint Commission Requirements

"…each protocol tested [must be] within 20 percent of the CTDIvol displayed on the CT console."

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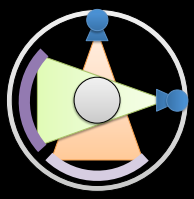
Siemens SOMATOM Force



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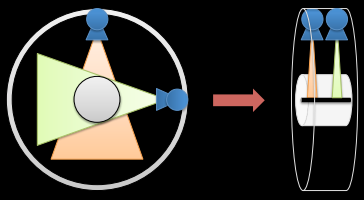
Dosimetry

Siemens tubes are offset in z-direction



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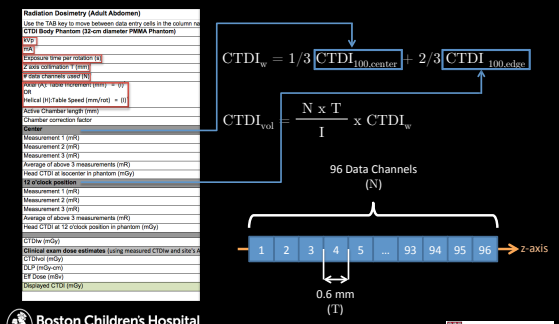
Dosimetry



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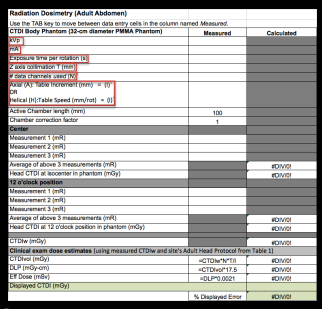
Dosimetry



Calculation	Scanner
1. kVp 2. mA 3. Rotation Time (s) 4. Z-axis collimation (mm) 5. # of data channels used 6. Table Increment / Speed	?

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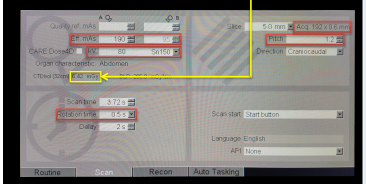
Dosimetry

Need two separate calculations!

Should add up to about



Calculation	Scanner
1. kVp 2. mA ⟷ 3. Rotation Time (s) 4. Z-axis collimation (mm) 5. # of data channels used 6. Table Increment / Speed ⟷	

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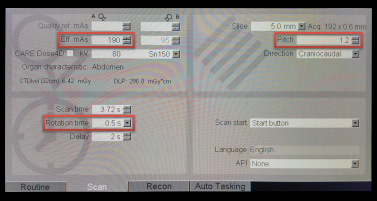
Dosimetry



$$mA = \frac{\text{Effective mAs x Pitch}}{\text{Rotation Time (s)}}$$

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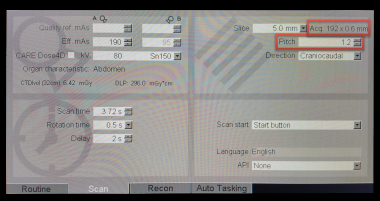
Dosimetry



$$I = \text{Pitch} \times N \times T$$

Dosimetry

Radiation Dosimetry (Adult Abdomen)

Use the TAB key to move between data entry cells in the column named *Measured*.

CTDI Body Phantom (32-cm diameter PMMA Phantom)	Measured	Calculated
kVp	80	
mA	456	
Exposure time per rotation (s)	0.5	
Z axis collimation T (mm)[1]	96	
# data channels used (N)[1]	0.6	
Axial (A): Table increment (mm) = (I)[1] OR Helical (H):Table Speed (mm/rot) = (I)[1]	69.12	
Active Chamber length (mm)	100	
Chamber correction factor	1	
Center		
Measurement 1 (mR)		
Measurement 2 (mR)		
Measurement 3 (mR)		
Average of above 3 measurements (mR)		#DIV/0!
Head CTDI at isocenter in phantom (mGy)		#DIV/0!
12 o'clock position		
Measurement 1 (mR)		
Measurement 2 (mR)		
Measurement 3 (mR)		
Average of above 3 measurements (mR)		#DIV/0!
Head CTDI at 12 o'clock position in phantom (mGy)		#DIV/0!
CTDIw (mGy)		#DIV/0!
Clinical exam dose estimates (using measured CTDIw and site's Adult Head Protocol from Table 1)		
CTDIvol (mGy)	=CTDIw*N*T/I	#DIV/0!
DLP (mGy-cm)	=CTDIvol*17.5	#DIV/0!
Eff Dose (mSv)	=DLP*0.0021	#DIV/0!
Displayed CTDI (mGy)		#DIV/0!
	% Displayed Error	#DIV/0!

Dosimetry

Radiation Dosimetry (Adult Abdomen)

Use the TAB key to move between data entry cells in the column named *Measured*.

CTDI Body Phantom (32-cm diameter PMMA Phantom)	Measured	Calculated
kVp	80	
mA	456	
Exposure time per rotation (s)	0.5	
Z axis collimation T (mm)[1]	96	
# data channels used (N)[1]	0.6	
Axial (A): Table increment (mm) = (I)[1] OR Helical (H):Table Speed (mm/rot) = (I)[1]	69.12	
Active Chamber length (mm)	100	
Chamber correction factor	1	
Center		
Measurement 1 (mR)	175	
Measurement 2 (mR)	174	
Measurement 3 (mR)	178	
Average of above 3 measurements (mR)		175.0
Head CTDI at isocenter in phantom (mGy)		2.6
12 o'clock position		
Measurement 1 (mR)	227	
Measurement 2 (mR)	226	
Measurement 3 (mR)	228	
Average of above 3 measurements (mR)		227.0
Head CTDI at 12 o'clock position in phantom (mGy)		3.4
CTDIw (mGy)		3.2
Clinical exam dose estimates (using measured CTDIw and site's Adult Head Protocol from Table 1)		
CTDIvol (mGy)	=CTDIw*N*T/I	2.6
DLP (mGy-cm)	=CTDIvol*17.5	46.2
Eff Dose (mSv)	=DLP*0.0021	0.1
Displayed CTDI (mGy)		6.42

Radiation Dosimetry (Adult Abdomen)

Use the TAB key to move between data entry cells in the column named *Measured*.

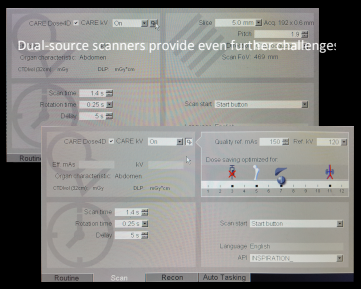
CTDI Body Phantom (32-cm diameter PMMA Phantom)	Measured	Calculated
kVp	150	
mA	226	
Exposure time per rotation (s)	0.5	
Z axis collimation T (mm)[1]	96	
# data channels used (N)[1]	0.6	
Axial (A): Table increment (mm) = (I)[1]	69.12	
Active Chamber length (mm)	100	
Chamber correction factor	1	
Center		
Measurement 1 (mR)	272	
Measurement 2 (mR)	273	
Measurement 3 (mR)	271	
Average of above 3 measurements (mR)		272.0
Head CTDI at isocenter in phantom (mGy)		4.1
12 o'clock position		
Measurement 1 (mR)	327	
Measurement 2 (mR)	326	
Measurement 3 (mR)	328	
Average of above 3 measurements (mR)		327.0
Head CTDI at 12 o'clock position in phantom (mGy)		4.9
CTDIw (mGy)		4.7
Clinical exam dose estimates (using measured CTDIw and site's Adult Head Protocol from Table 1)		
CTDIvol (mGy)	=CTDIw*N*T/I	3.9
DLP (mGy-cm)	=CTDIvol*17.5	68.0
Eff Dose (mSv)	=DLP*0.0021	0.1
Displayed CTDI (mGy)		6.42

Tube A: 2.6 mGy

Tube B: 3.9 mGy

Total: 6.5 mGy
Display: 6.42 mGy

Dosimetry



Dosimetry

Radiation Dosimetry (Adult Body)

Use the TAB key to move between data entry cells in the column named *Measured*.

CTDI Body Phantom (32-cm diameter PMMA Phantom)	Measured	Calculated
kVp	120	
mA	532	
Exposure time per rotation (s)	0.5	
Z axis collimation T (mm)	0.6	
# data channels used (N)	96	
Axial (A): Table Increment (mm) = (I)		
OR		
Helical (H):Table Speed (mm/rot) = (I)	109.44	
Active Chamber length (mm)	100	
Chamber correction factor	1	
Center		
Measurement 1 (mR)	748.4	
Measurement 2 (mR)	746.5	
Measurement 3 (mR)	746.8	
Average of above 3 measurements (mR)		746.2
Body CTDI at isocenter in phantom (mGy)		11.3
12 o'clock position		
Measurement 1 (mR)	1413	
Measurement 2 (mR)	1414	
Measurement 3 (mR)	1414	
Average of above 3 measurements (mR)		1413.7
Body CTDI at12 o'clock position in phantom (mGy)		21.4
CTDIw (mGy)		18.0
Clinical exam dose estimates (using measured CTDIw and site's Adult Abdomen Protocol from Table 1)		
CTDIvol (mGy)	=CTDIw*k*f1	9.5
DLP (mGy-cm)	=CTDIvol*25	236.8
Eff Dose (mSv)	=DLP*0.015	3.6
Displayed CTDI (mGy)*		9.4
	% Displayed Error	1.17

Option 1:
Half the mA, twice the time
Same mAs

Option 2:
Half the mA, same time
Double the mR measurements

Option 3:
Half the mA, same time
Take two mR measurements and sum them

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Thank You!

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