THE UNIVERSITY OF TEXAS MD Anderson Cancer Center
Making Cancer History®

Quantitative MECT Material Suppression

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American Association of Physicists in Medicine
59th Annual Meeting
August 2, 2017

Outline

Multi-energy CT review
- Quantification
- Material suppression

Metal artifact reduction

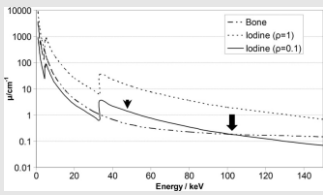
Iodine Suppression

Bone Removal and Calcium Suppression

CT Material Suppression and Quantification

Conventional CT
- Voxel represents sum of linear attenuation coefficient for different materials
- Various materials can't be differentiated or quantified

Multi-Energy CT
- Two polyenergetic spectra are acquired providing unique attenuation coefficients for differing materials at various energies
- Each material has a strong energy dependency
  - Photoelectric → atomic number (Z)
  - Compton → electron density (ρ_e)



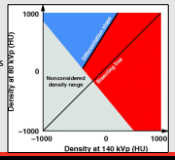
McCollough C, *et al.* Radiology 2015

MECT Material Decomposition

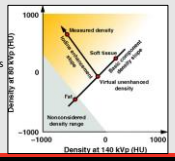
Virtual monochromatic images are synthesized from MECT data in either the image or projection domain

$$\mu(E) = \left[\frac{\mu}{\rho}\right]_1(E) \cdot \rho_1 + \left[\frac{\mu}{\rho}\right]_2(E) \cdot \rho_2$$

2 Basis Materials



3 Basis Materials



Johnson TRC, AJR. 2012

MECT Opportunities in Therapy

Attenuation coefficient allows parameterization as a function

- Atomic number, Z_{eff}
- Electron density, ρ_e

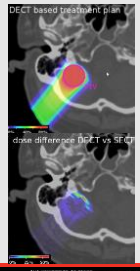
$$\mu(E) = \frac{a\rho_e Z_{eff}^c}{E^b} + \sigma_{KN}(E)\rho_e + \frac{e\rho_e Z_{eff}^d}{E^f}$$

Variables a-f are best fit material and energy independent parameters

σ_{KN} is the Klein-Nishina cross section for Compton scattering

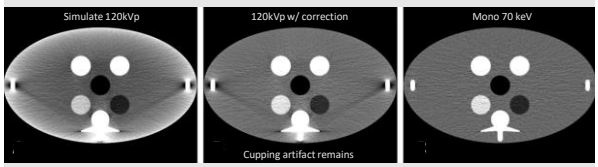
Dose uncertainty reduced from 11% to 1% (Tsukihara M, *et al.* Med Phys. 2015)

Projection based dual-energy material decomposition algorithms can be limited by data consistency between the high and low energy projections



van Elmpt W, *et* al. Radiotherapy and Oncology, 2016; Hudobivnik N, *et al.* Med Phys 2016

Beam Hardening Artifact



Beam hardening artifact eliminated!

Yu L, *et al.* AJR 2012

Metal Artifact Reduction

Approaches to Reduce Metal Artifacts

Conventional single-energy CT

Metal Artifact Reduction (MAR) Reconstruction

Multi-energy CT (Monochromatic imaging)

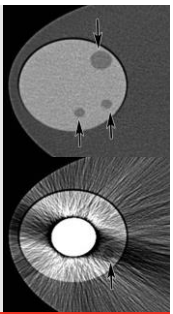
Multi-energy CT + MAR reconstruction

Metal Artifact Physical Effects

Beam Hardening
- The low energy photons are preferentially absorbed
- Transmitted high energy photons do not provide adequate image quality, especially for soft tissues

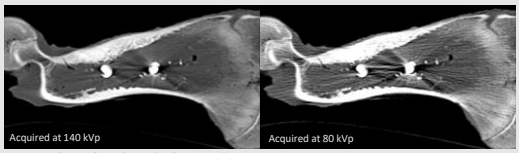
Undersampling
- Large density differences in metal and surrounding tissue are not sufficiently sampled

Photon Starvation
- Only a few photons are detected leading to high statistical uncertainty



Subas N *et al*. AJR. 2016

Conventional Acquisition Considerations



Increasing kVp reduces beam hardening and noise
- Low contrast is compromised from the increase in kVp

Other considerations:
- Increase mA to lower noise
- Lower pitch to reduce noise
- Decrease slice thickness to reduce partial volume artifact
- Extend CT scale to increase window width and level

Lee M *et al*. Radiographics. 2007

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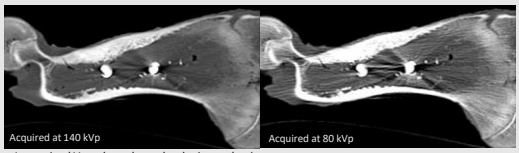

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➡ **Increased Dose**

Lee M *et al*. Radiographics. 2007

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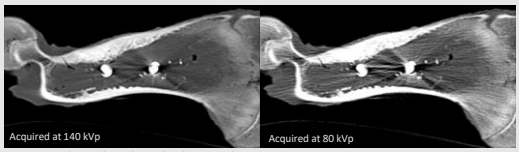

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➡ **Increased Dose**

Doesn't cut it!!!

Lee M *et al*. Radiographics. 2007

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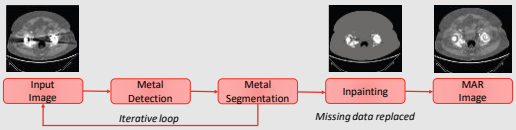
Reconstruction Approaches



Performed in image space, projection space or combination

Iterative loop for metal detection and segmentation provides improved characterization of the metal material along with adjusted beam hardening corrections.

Missing data near the metallic object must be filled in and each vendor uses a proprietary method to re-establish the image quality

Images borrowed from Phillips O-MAR white paper

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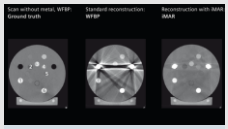
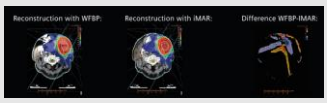
MAR and Treatment Plan Dosimetry Considerations

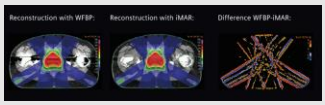


Insert #	Description	Ground Truth (GT)	Weighted Filtered Back Projection (WFBP)	attenuation deviation (|GT − WFBP| ÷ (1000 + GT))	iMAR	attenuation deviation (|GT − iMAR| ÷ (1000 + GT))
1	CB2-30%	414 HU	288 HU	10%	391 HU	2%
2	Adipose	-90 HU	-507 HU	46%	-59 HU	3%
3	Inner Bone	197 HU	376 HU	15%	201 HU	0.30%
4	Liver	64 HU	-366 HU	40%	78 HU	1%
5	Breast	-41 HU	-136 HU	10%	-35 HU	0.60%
6	CB2-50%	675 HU	575 HU	6%	671 HU	0.20%

Improved CT Number Accuracy



Potential Dose Discrepancy up to 4% with WFBP



Potential Dose Discrepancy up to 5% with WFBP

Siemens Healthineers iMAR White Paper. Analysis courtesy DKFZ Germany

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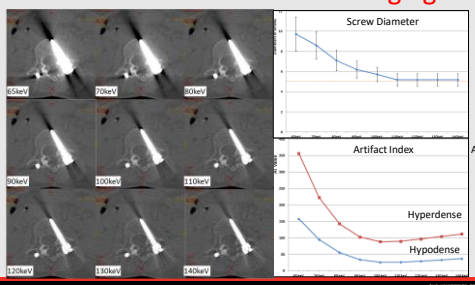
MECT Monochromatic Imaging



$AI = \sqrt{SD_a - SD_b}$

Wang Y, *et al.* E J Radiol 2013

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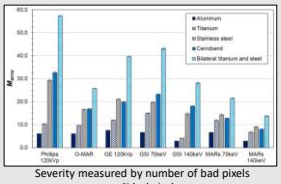
Quantification Errors

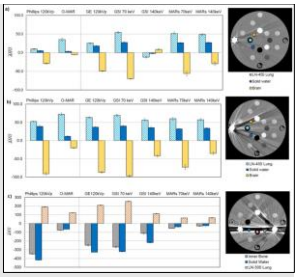
RMI phantom imaged with different metal insert

Compared conventional CT, MAR, monoenergetic imaging, and monoenergetic imaging with MAR



Severity measured by number of bad pixels

$$M_{error} = (\text{HU}>40)\frac{\%\ bad\ pixels}{100} * \Delta HU_{badpixels}$$



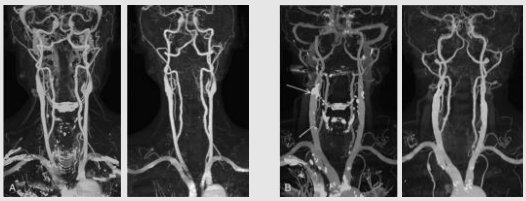
CT Number Accuracy

$$\Delta HU = HU_{metal} - HU_{baseline}$$

Huang JY, *et al.* Phys Med Biol. 2015

Bone Removal, Calcium Suppression and Quantification

MECT Bone Removal



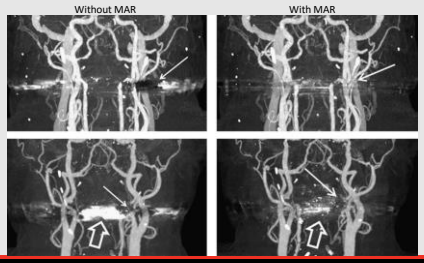
MECT acquisition evaluating automated bone removal and amount of manual optimization

A: Automated removal (4 min, 10 sec) and manual optimization (5 min, 20 sec)

B: Automated removal (2 min, 6 sec) and manual optimization (8 min, 45 sec)

Kaemmer N, *et al.* Invest Radiol. 2016

MECT Bone Removal and MAR



Kaemmer N, *et al.* Invest Radiol. 2016

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MECT Bone Mineral Density Quantification

3-Basis Materials: Water, K2HPO4 and MAT

Conventional BMD quantification limited by marrow adipose tissues (MAT)

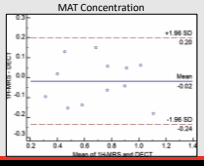
$$\rho_{H2O} = \frac{1}{D}\cdot[\beta_{K2HPO4,140}\cdot(CT_{80} - c_{80}) - \beta_{K2HPO4,80}\cdot(CT_{140} - c_{140})]$$

$$\rho_{K2HPO4} = \frac{1}{D}\cdot[\beta_{H2O,80}\cdot(CT_{140} - c_{140}) - \beta_{H2O,140}\cdot(CT_{80} - c_{80})],$$

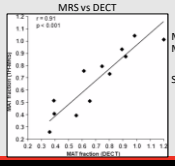
$$D = \beta_{H2O,80}\cdot\beta_{K2HPO4,140} - \beta_{H2O,140}\cdot\beta_{K2HPO4,80}$$

Mindways QCT Phantom

MAT Concentration



MRS vs DECT



MECT has advantage compared to MRS – single voxel vs. volume

Single vs dual-energy difference

- Mean: -35.9 mg/cm^3 (-27.2%) @ 95% confidence interval

Bradella MA, *et al.* Radiology. 2015

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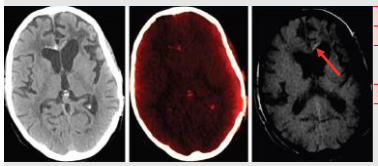
MECT Calcium Suppression

3-Basis Materials: Brain Parenchyma, Hemorrhage and Calcium



Single-energy CT | Calcium Overlay | VNC

	Calcification	Hemorrhage
DE CT		
Calcification	41	1
Hemorrhage	0	26
SE CT		
Calcification	39	2
Hemorrhage	1	20
Indeterminate	1	5

Differentiating intracranial calcification and hemorrhage on unenhanced conventional CT is challenging

Calcified depositions can have varying amounts of calcium resulting in overlapping CT numbers with hemorrhage on conventional CT

Hu R, *et al.* Radiology. 2016

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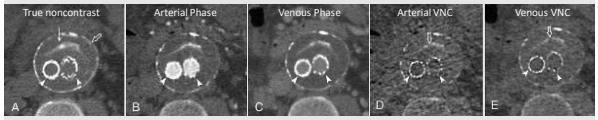
Iodine Suppression and Quantification

MECT Iodine Suppression

Basis Materials: Water and Iodine



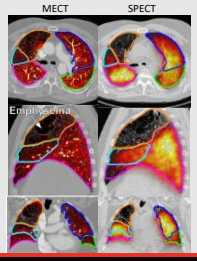
VNC Sensitivity: 83.3% and 75.0% (arterial phase); 95.8% and 87.5% (venous phase)

Contributors to sensitivity difference include image noise, reliability of material decomposition, and reliability of iodine subtraction at different concentrations.

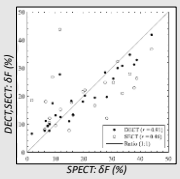
	Scan Type		
	SE triphasic	DE monophasic	DE biphasic
Mean Eff Dose (mSv)	39.7	14.1	23.3

Maturen, KE, *et al.* JCAT. 2011

MECT Iodine Quantification – Pulmonary Function



$$\overline{\delta F} = \frac{\sum_{v \in V} \sum_{E \in \varepsilon} F_E}{\sum_{v \in V_{Lung}} \sum_{E \in \varepsilon} F_E}$$



Evaluation of pulmonary function can optimize dose planning and reduce pulmonary toxicities

MECT performed at exhale to minimize respiratory motion

SPECT is free breathing acquisition

Differences in acquisition could partially explain variation in calculated differential function

Lapointe A, *et al.* Med Phys. 2017