Application of DECT in Modern Radiation Therapy

AMAZING THINGS ARE HAPPENING HERE

Hansen Chen
Director, Technology Development & Systems Integration
Combined Radiation Oncology Department

NewYork-Presbyterian
The University Hospital of Columbia and Cornell

Contributions

- **Dr. Lei Dong, Scripps Proton Therapy Center**
- **Dr. Chris Amies et. al., Siemens Medical Clinical Science**
- **NYP Columbia Physics Team**
  - Dr. Rompin Shih, Muhammad Afghan, Pei Fan,
  - Dr. Zheng Jin, Archie Chu, Ping Yan

Novel Imaging Application in Radiotherapy

- **Computer Tomography Imaging**

Dual Energy CT

In-Room CT-on-Rail

Novel Imaging Application in Radiotherapy

- **Magnetic Resonance Imaging**

MR-Guide Linac

MR-Guide Co-60

MR-on-Rail

Novel Imaging Application in Radiotherapy

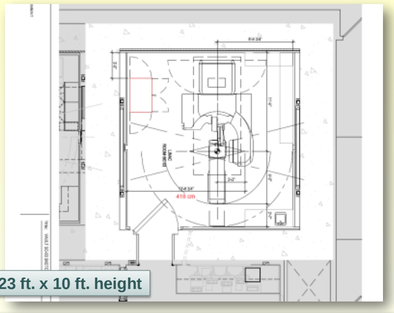
- **Molecular Imaging**

PET / CT

SPECT

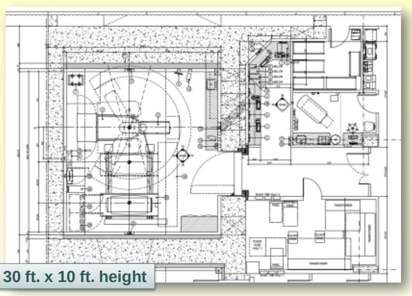
Will it Fit?

Linac Vault Drawing



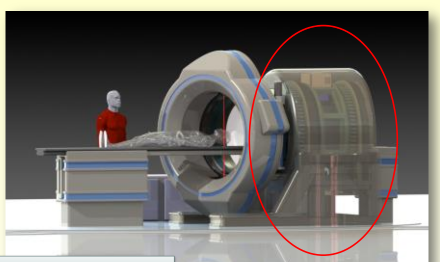
~ 23 ft. x 23 ft. x 10 ft. height

CT-on-Rail Drawing



~ 30 ft. x 30 ft. x 10 ft. height

ArcKnife – Inline CT

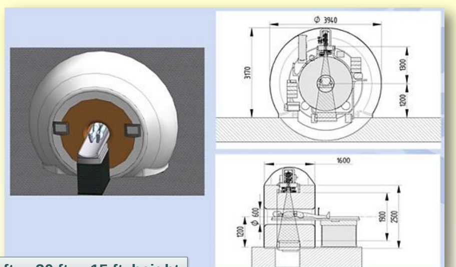


~ 25 ft. x 25 ft. x 10 ft. height

MR-on-Rail

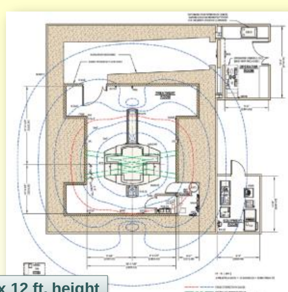
~ 75 ft. x 23 ft. x 15 ft. height

MR-Guided Linac



~ 30 ft. x 30 ft. x 15 ft. height

MR-Guided Co-60



~ 30 ft. x 33 ft. x 12 ft. height

Also Administrative Considerations

- **Staff Training**
  - MRI, PET for Radiation Therapist
- **Administrative Rule of Thumb**

$$Value = \frac{Procedure\ Volume \otimes CPT\ Codes}{Patient\ Risks}$$

- **And Benefits Bringing On-Board**
  - Research
  - Education
  - Clinical Outcome(s)

CT!

DECT in Modern Radiation Therapy

- **Pre-Treatment CT Simulation**
  - Different Approaches to Accomplish DECT
    - Sequential
    - Simultaneous (w/ Different Implementations)
- **Target & Critical Organ Delineation**
  - Dual Energy CT Imaging Capabilities
    - Material Decomposition
    - Material Labeling
    - Material Highlighting
  - Reduction in Metal Artifacts
  - Virtual Contrast Removal, Iodinated Contrast Enhancement
  - Biological / Functional Imaging to be Discussed in Quantitative Session

DECT in Modern Radiation Therapy

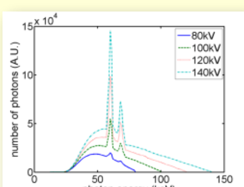
- **Dose Computation**
  - Insensitive to MV x-rays (Compton Interaction)
  - Sensitive to particle therapy and low energy brachytherapy (Z-dependence), Atomic number etc.
  - Derive proton stopping power ratios of different biological tissues
- **During Treatment Adaption**
  - Adaptive Therapy Hurdles
    - Accuracy of Deformable Image Registration
    - Dose Deformation Uncertainty

DECT in Modern Radiation Therapy

- **Quantitative Outcome Analysis**
  - Dual Energy is a Tool that can be Used to Evaluate the Chemical Composition of Body Tissue
  - Tissue Characterization
  - Virtual Contrast Removal
  - Iodinated Contrast Enhancement
  - Tumor's Biological Characterization Assessment during and after The Treatment Completion by Perfused Blood Volume Imaging
  - Xenon Imaging (Ventilation)
- **Biologically Guided Radiation Therapy (BGRT)**

Pre-Treatment CT Simulation

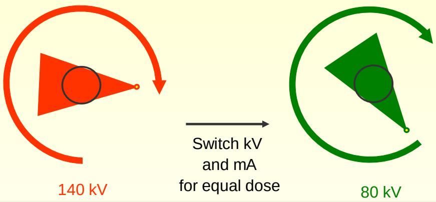
- **DECT: Dual X-Ray Spectra**
  - Sequential
  - Simultaneous (w/ Different Implementations)



Slide curtsey of Siemens Medical

Sequential Scans with Different kV

- A (partial) scan is performed with one kV-setting (e. g. 140 kV)
- kV and mA are switched
- A second (partial) scan is performed at the same z-position, with the other kV-setting (e. g. 80 kV) and the other mA-setting



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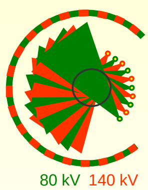
Fast kV-Switching During One Scan

- The tube voltage (kV) is switched between two readings (e.g. from 140 kV to 80 kV)
- Two “interleaved“ data sets with different kV-settings are simultaneously acquired



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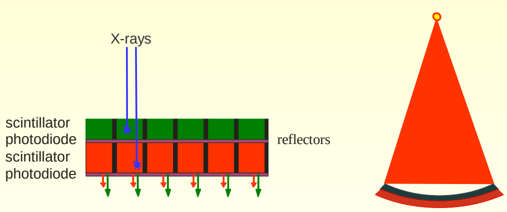
Dual Layer Detectors

- Sandwich-type detector, two layers per channel
- Detection of lower energy quanta in the top layer
- Detection of higher energy quanta in the bottom layer



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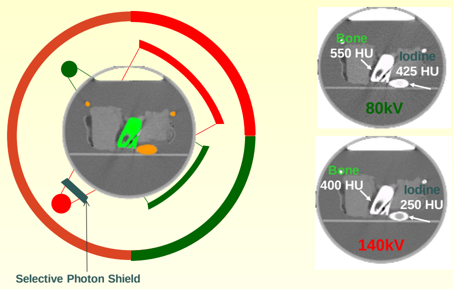
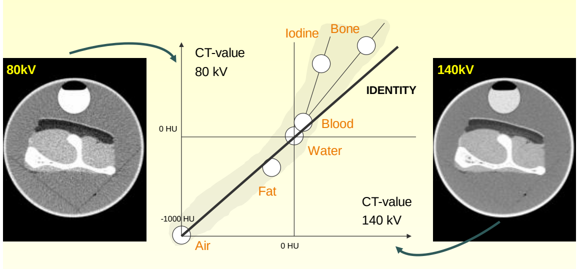
Dual Source CT



Target & Critical Organ Delineation

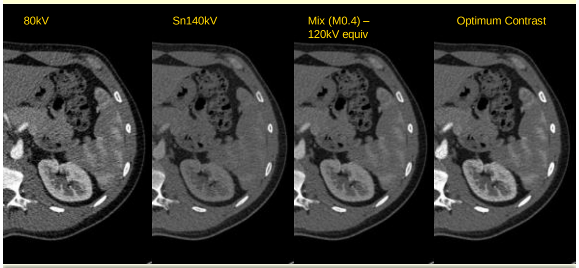
- Dual Energy CT Imaging Capabilities
- Reduction in Metal Artifacts
- Virtual Contrast Removal and Iodinated Contrast Enhancement
- Biological and Functional Imaging to be Discussed Later

Dual Energy CT Value Differentiation



Linear & Non-Linear CT Data Mixture

- At low ct-values: show noise optimized mixed image
- At high ct-values: show low kv image
- In between: linear increase in de-composition with ct-value



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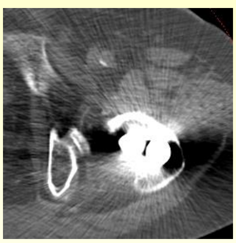
Metal Artifact Reduction



Standard Recon

120 keV Monoenergetic

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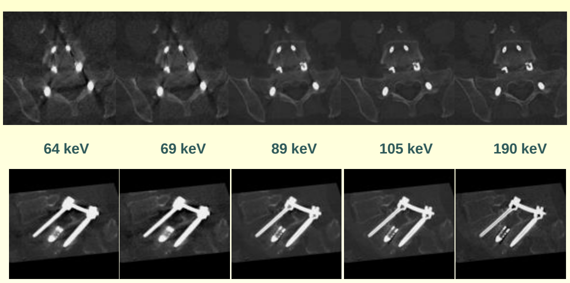
Metal Artifact Reduction vs. Energy



Slide Courtesy of Thorsten Johnson (University Hospital Großhadern, Germany)

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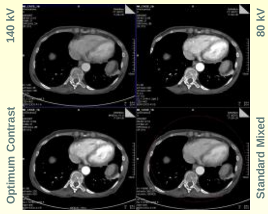
CT Data Mixture Capabilities

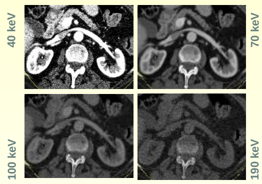
Non-Linear Optimum Contrast

Combines high iodine contrast of 80 kV with low noise of 140 kV into a single dataset



Monoenergetic Images

Images of 151 energies can be calculated out of Dual Energy datasets (40 – 190 keV)



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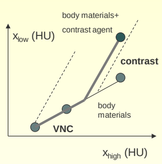
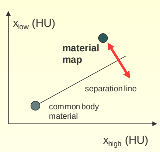
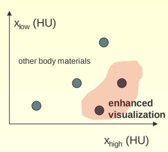
Dual Energy CT Imaging Capabilities







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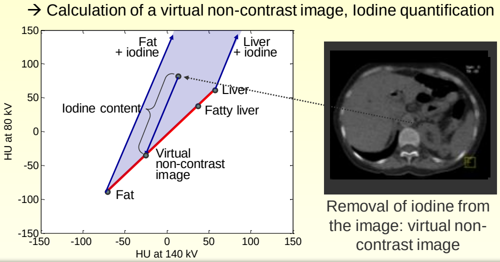
Virtual Non-Contrast Image and Iodine Image

Most promising application: 3-material decomposition

→ Fat, liver and Iodine

→ Calculation of a virtual non-contrast image, Iodine quantification



Removal of iodine from the image: virtual non-contrast image

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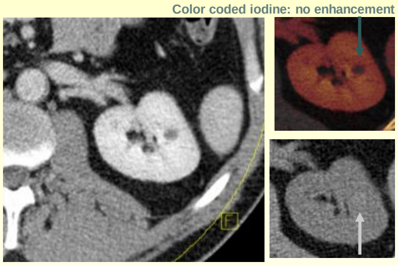
Virtual Unenhanced: Isodense to Renal Parenchyma

Color coded iodine: no enhancement

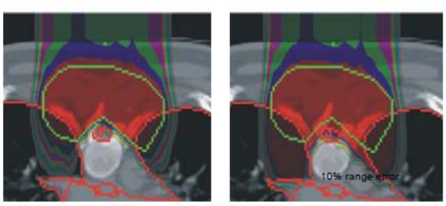


Slide curtsey University of Munich, Grosshadern Hospital/ Munich, Germany

Dose Computation

- Insensitive to MV X-rays (Compton Interaction)
- Sensitive to Particle Therapy and Low Energy Brachytherapy (Z-dependence), Atomic Number etc.
- Derive Proton Stopping Power Ratios of Different Biological Tissues

Errors in Proton Dose Computation



The advantage of protons is that they stop.

The disadvantage of protons is that we don't always know where…

Lomax: PTCOG47

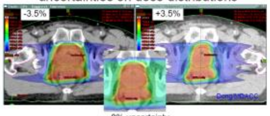
Impact of CT HU Uncertainties

Comprehensive analysis of proton range uncertainties related to patient stopping-power-ratio estimation using the stoichiometric calibration

M Yang1,2, **X R Zhu**1,2, **PC Park**1,2, **Uwe Titt**1,2, **R Mohan**1,2, **G Virshup**3, **J Clayton**3, and **L Dong**1,2
1,2 The University of Texas MD Anderson Cancer Center,
3 Ginzton Technology Center, Varian Medical Systems, 3120 Hansen Way, Palo Alto, CA 94303, USA

"The SPR uncertainties (1σ) were quite different (ranging from 1.6% to 5.0%) in different tissue groups, although the final combined uncertainty (95th percentile) for different treatment sites was fairly consistent at **3.0–3.4%,** primarily because soft tissue is the dominant tissue type in human body"

Impact of CT Hounsfield number uncertainties on dose distributions



0% uncertainty

Individualized patient determination of tissue composition along the complete beam path, rather than CT Hounsfield numbers alone, would probably be required even to reach "sub-centimeter precision"

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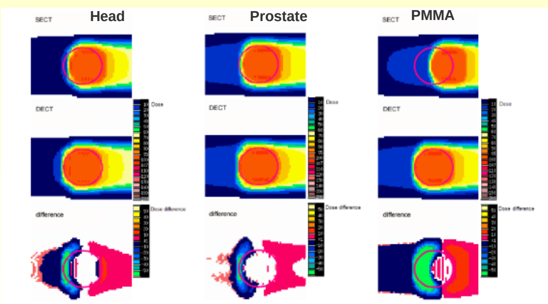
Dose Difference: SECT vs. DECT



Nora Hunemohr et al. PMB 59 (2014) 83-96

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What Do We Need To Know?

- **Requires a detailed knowledge of the tissue that will be irradiated.**
  - Ideally the elemental composition and mass density should be known
- **Knowing the effective atomic number (Z) and the relative electron mass density (rho) of the material may help to more accurately predict the stopping power ratio.**

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Stopping Power Ratio (SPR)

- **The Bethe-Bloch equation**

$$SPR = EDR \times \frac{\ln[2m_e c^2 \beta^2 / I_m (1-\beta^2)] - \beta^2}{\ln[2m_e c^2 \beta^2 / I_{water} (1-\beta^2)] - \beta^2}$$

- **Use dual energy CT (DECT) to estimate SPR**
  - Calculate electron density ratio (EDR) and effective atomic number (EAN) for each voxel

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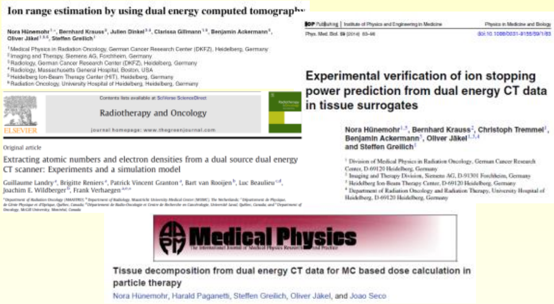
Electron Density Ratio / Effective Atomic Number



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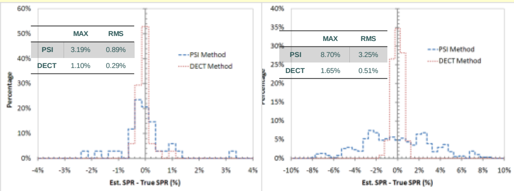
Improvement in SPR Calculation using DECT



The histograms of relative errors in the SPRs estimated using the PSI method (Stoichiometric Method) and the DECT method, respectively.

a) is for 34 standard human biologic tissues as listed in *ICRP 23* and *ICRU 44*;
b) is for human biological tissues generated from standard human biological tissues by introducing small variations to their densities and element compositions.

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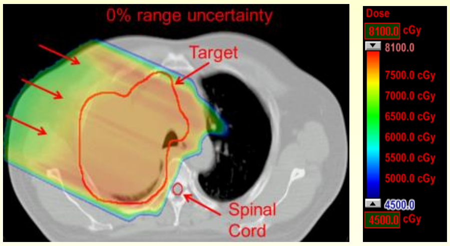
Impact of 3.5% Range Uncertainty

- **Uncertainty in SPR Estimation**
  - Estimated to be 3.5% (Moyers *et al,* 2001, 2009)



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Reduction of Range Uncertainty Using DECT

- **Conventional Margin: 3.5%**
- **Proposed Margins**
  - Prostate: 2.0%
  - Lung: 2.5%
  - HN: 2.0%

SPR Uncertainty (1-SD)			Range Uncertainty (2-SD)		
Lung	Soft	Bone	Prostate	Lung	HN
3.8%	0.99%	1.4%	1.9%	2.3%	1.9%

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During Treatment Adaption

- **Adaptive Therapy Hurdles**
  - Accuracy of Deformable Image Registration
  - Dose Deformation Uncertainty

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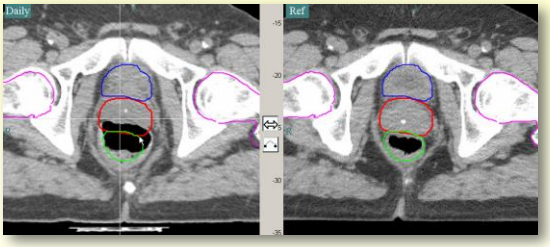
Hurdles to Adaptive Therapy

- **Accuracy of Deformable Image Registration**
  - Soft tissue discrimination



Hurdles to Adaptive Therapy

- **Dose Deformation Uncertainty**
  - Especially for the homogeneous region of interest

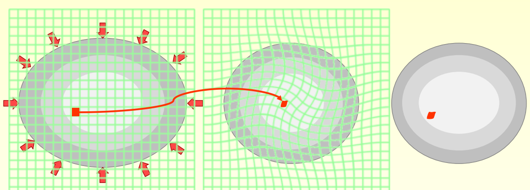
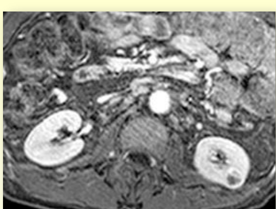


Image Enhancement to Increase Image Data Differentiation



MR Image

DECT Monoenergetic 40 keV

Is Dose Distribution the Only Justification?

- Why we are doing IMRT? … Dose Distribution
- Why we are charging for IMRT? … Dose Distribution
- Why we are using Proton Therapy? … Dose Distribution
- Why Proton machine is expensive? … Dose Distribution
- Why we are doing IGRT … Dose Distribution
- Why we are doing Adaptive Therapy? … Dose Distribution
- Why we come to AAPM conference? -------

Quantitative Outcome Analysis

- Dual Energy is a Tool that can be Used to Evaluate the Chemical Composition of Body Tissue
- Tissue Characterization
- Iodinated Contrast Enhancement
- Tumor's Biological Characterization Assessment during and after The Treatment Completion by Perfused Blood Volume Imaging
- Xenon Imaging (Ventilation)

Imaging Biomarker: Treatment Response


Contents lists available at SciVerse ScienceDirect
European Journal of Radiology
journal homepage: www.elsevier.com/locate/ejrad

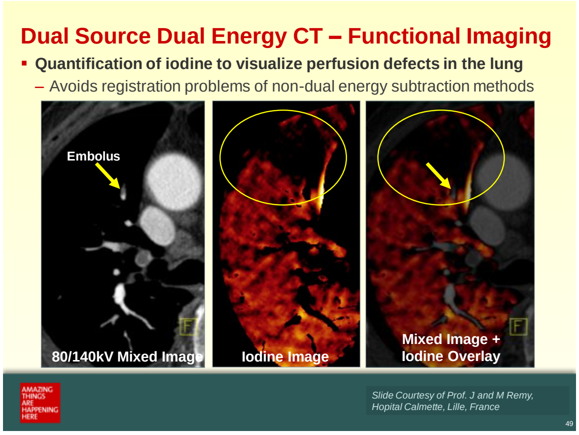
Quantitative therapy response assessment by volumetric iodine-uptake measurement: Initial experience in patients with advanced hepatocellular carcinoma treated with sorafenib

Xu Dai[a,b], Heinz-Peter Schlemmer[b], Bernhard Schmidt[c], Karolin Höh[d], Ke Xu[a], Tom M. Ganten[d], Maria-Katharina Ganten[b,*]


Contents lists available at SciVerse ScienceDirect
European Journal of Radiology
journal homepage: www.elsevier.com/locate/ejrad

CT-based response assessment of advanced gastrointestinal stromal tumor: Dual energy CT provides a more predictive imaging biomarker of clinical benefit than RECIST or Choi criteria

M. Meyer[a,*], P. Hohenberger[b,2], P. Apfaltrer[a,1], T. Henzler[a,1], D.J. Dinter[a,1], S.O. Schoenberg[a,1], C. Fink[a,1]


Dual Source Dual Energy CT – Functional Imaging
Quantification of iodine to visualize perfusion defects in the lung
– Avoids registration problems of non-dual energy subtraction methods
Embolus
80/140kV Mixed Image
Iodine Image
Mixed Image +
Iodine Overlay
Slide Courtesy of Prof. J and M Remy,
Hopital Calmette, Lille, France
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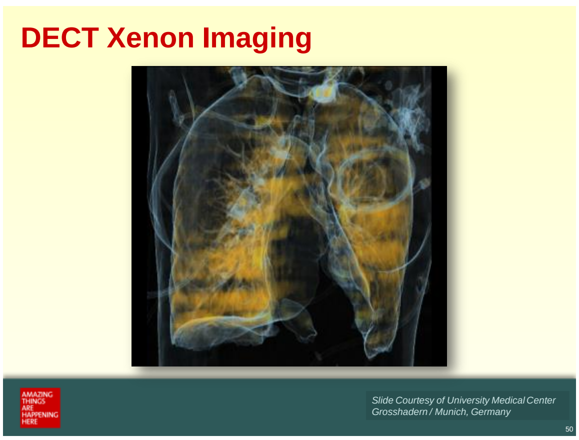
DECT Xenon Imaging
Slide Courtesy of University Medical Center
Grosshadern / Munich, Germany
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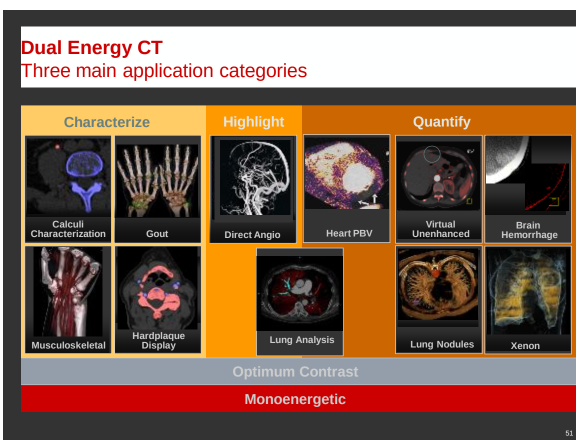
Dual Energy CT
Three main application categories
Characterize
Highlight
Quantify
Calculi
Characterization
Gout
Direct Angio
Heart PBV
Virtual
Unenhanced
Brain
Hemorrhage
Musculoskeletal
Hardplaque
Display
Lung Analysis
Lung Nodules
Xenon
Optimum Contrast
Monoenergetic
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Conclusion

- B.G.R.T.
- Biologically Guided Radiation Therapy

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