Multi-Energy CT: Technology, Applications and Future Directions

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Single Energy CT (SECT)

- Single X-ray source
- Single sinogram
- X-ray attenuation influenced by different materials

Lesion to background contrast

Role of Contrast Media
SECT Challenges

- Small lesion detection and characterization
- Non-contour deforming lesions
- Tissue characterization
- Inflammation vs tumor
- Peritoneal implants vs Ascites
- Post operative change vs. recurrence
- Response
- Material Separation

What is the advantage of Dual Energy CT?

DECT provides more information about tissues than SECT

It uses attenuation measurements acquired with different energy spectra, and knowledge of the changes in attenuation between the two spectra is used to assess tissue and material composition.

Johnson TRC. Eur Radiology 2007
Stollerm P Radiology 2008
Ascenti G, AJR 2011
Megibow A and Sahani DV . AJR 2012
Agrawal M et al. Radiographics 2014
Materials Evaluated On CT

- Iodine - CM enhancement +/-
  - (Z=53)
- Calcium-plaques/stones/bones/lesion
  - (Z=20)
- Soft tissues
  - hydrogen (Z=1), carbon (Z=6), nitrogen (Z=7) and oxygen (Z=8)

The principles of DECT is based on varying behavior of materials when exposed to different x-ray photon energies.

**DECT approach**

1. Soft tissue
2. Fat
3. Calcium

**Material decomposition algorithm**

1. Water
2. Iodine
3. Other base pairs (Iodine: calcium)

**Images generated**

<table>
<thead>
<tr>
<th>No.</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Soft tissue</td>
</tr>
<tr>
<td>2</td>
<td>Fat</td>
</tr>
<tr>
<td>3</td>
<td>Calcium</td>
</tr>
</tbody>
</table>

**DECT: MD-Iodine (Water Extraction)**

Agrawal M et al. Radiographics 2014.
DECT: Virtual Unenhanced Images (Iodine Extraction)

<table>
<thead>
<tr>
<th>Indication</th>
<th>TNC</th>
<th>MD Water</th>
<th>CECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Renal Stone</td>
<td><img src="#" alt="Image 1" /></td>
<td><img src="#" alt="Image 2" /></td>
<td><img src="#" alt="Image 3" /></td>
</tr>
<tr>
<td>Renal Mass</td>
<td><img src="#" alt="Image 4" /></td>
<td><img src="#" alt="Image 5" /></td>
<td><img src="#" alt="Image 6" /></td>
</tr>
<tr>
<td>Adrenal Lesion</td>
<td><img src="#" alt="Image 7" /></td>
<td><img src="#" alt="Image 8" /></td>
<td><img src="#" alt="Image 9" /></td>
</tr>
</tbody>
</table>

DECT- Virtual Monochromatic Images

GSI Spectrum (80/140 kV)

“GSI acquisition is almost similar to SECT but rigorous analysis is performed on the images”
DECT scanners

Rotate-rotate
(Toshiba)

Dual Source
(Siemens)

Rapid kVp switching
(General Electric)

Sandwich detector
(Philips)

Twin beam
(Siemens)

Photon Counting

Continuous growth and development of DECT technology and adoption in research and clinical realm

Prospective Acquisition

Retrospective DECT

DECT scanners

Rotate-rotate
(Toshiba)

Dual Source
(Siemens)

Rapid kVp switching
(General Electric)

Sandwich detector
(Philips)

Twin beam
(Siemens)

Photon Counting

Courtesy of Ben Yeh, UCSF
Potential Benefits of Spectral CT

- Better tissue characterization
- Easier diagnosis
- Minimize additional tests: cost savings/dose
- Reduced acquisition phases
- Superior vascular imaging
  - Vessels and concurrent tissue perfusion maps
- Material separation
- Iodine dose reduction
- Metal artifact reduction

Pubmed – Dual energy CT

1980 publications

45Y Women with right chest wall trauma

Multiple right ribs fractures
Renal Laceration?

**140 kV GSI**

**VNC**  MD-Iodine

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**RCC**

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Renal Lesion vs Hemorrhage

Case #1

TNC  CECT  MDI

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Case #2

TNC  CECT  MDI


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Renal Mass Characterization

<table>
<thead>
<tr>
<th>TNC</th>
<th>CECT</th>
<th>MD Iodine</th>
<th>Iodine map</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small cyst</td>
<td>![Small Cyst Image]</td>
<td>![Small Cyst Image]</td>
<td>![Small Cyst Image]</td>
</tr>
<tr>
<td>Renal mass</td>
<td>![Renal Mass Image]</td>
<td>![Renal Mass Image]</td>
<td>![Renal Mass Image]</td>
</tr>
<tr>
<td>Hyperdense cyst</td>
<td>![Hyperdense Cyst Image]</td>
<td>![Hyperdense Cyst Image]</td>
<td>![Hyperdense Cyst Image]</td>
</tr>
</tbody>
</table>
Hypervascular Liver Lesions

Liver DECT and Hypervascular Lesions Detection

<table>
<thead>
<tr>
<th>Hypervascular lesion with DECT in arterial phase</th>
<th>Muenzel et al. 2009</th>
<th>31</th>
<th>DECT and MD-I (65 keV)</th>
<th>MD-I (65 keV) improved sensitivity of hypervascular lesions over SECT and MD-I (65 keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abunnel et al. 2011</td>
<td>40</td>
<td>DECT (65 keV)</td>
<td>Hypervascular lesions detection improved over MD-I (65 keV)</td>
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<tr>
<td>Shriram et al. 2014</td>
<td>72</td>
<td>DECT (65 keV)</td>
<td>Hypervascular lesions detection improved over MD-I (65 keV)</td>
<td></td>
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<tr>
<td>Abunnel et al. 2016</td>
<td>20</td>
<td>Uveal melanoma</td>
<td>MD-I (65 keV) improved sensitivity of hypervascular lesions detection over DECT (65 keV)</td>
<td></td>
</tr>
</tbody>
</table>

DECT and CE-Liver MRI

- 52 patients
  - 236 hypervascular lesion (31 Benign and 205 Malignant)
  - 3 Readers (3 Read sessions - SECT, 65 kEV and MD-I)
  - Lesion detection superior on MD-I for all readers (80% vs 65%)
  - Higher lesion to liver CNR

Muenzel D et al. European Jour of Radiol 2017
Pfifer D et al. Abdominal Imaging 2018
Liver Nodule Characterization in 55 yr-old man with HBV cirrhosis

Treatment monitoring – RFA HCC and RCC

65 year old with loss of weight
Poratli Phase Dual Energy CT: Small PDAC

CT Performance for PDAC Diagnosis-Staging

<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>Phase</th>
<th>CT</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluemke et al.</td>
<td>64</td>
<td>Mps</td>
<td>89%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ichikawa et al.</td>
<td>21</td>
<td>Bps</td>
<td>76.2%</td>
<td>58%</td>
<td></td>
</tr>
<tr>
<td>Irie et al.</td>
<td>8</td>
<td>Bps</td>
<td></td>
<td>62.5%</td>
<td></td>
</tr>
<tr>
<td>Diehl et al.</td>
<td>76</td>
<td>Bps</td>
<td>97%</td>
<td></td>
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<tr>
<td>Legman et al.</td>
<td>27</td>
<td>Bts</td>
<td>92%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sheridan et al.</td>
<td>31</td>
<td>Bps</td>
<td>93.5%</td>
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<td></td>
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<tr>
<td>Bronstein 2003</td>
<td>18</td>
<td>Tps Ss/mt</td>
<td>77%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fletcher 2003</td>
<td>30</td>
<td>Tps Ss/mt</td>
<td>97%</td>
<td></td>
<td></td>
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<tr>
<td>Takakura et al.</td>
<td>32</td>
<td>Tps</td>
<td>94%</td>
<td></td>
<td></td>
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<tr>
<td>Prochowski et al.</td>
<td>117</td>
<td>Mp(PVP) Ss</td>
<td>95%</td>
<td>98.8%</td>
<td>96.4%</td>
</tr>
</tbody>
</table>

MP: Monophasic examination; BP: Biphasic examination; TP: Triphasic examination; SSCT: single slice CT; TSCT: two slice CT; MSCT: multislice (>4) CT; M: malignancies

DECT: Pulmonary embolism with segmental defects on PBV image (no infarction)
DECT: Pulmonary embolism with segmental defects on PBV image (no infarction)

Radiation Dose

Our institutional data and prior studies demonstrate that chest DECT can have similar or lower radiation doses as compared to the single energy CT.

<table>
<thead>
<tr>
<th>Pulmonary embolism protocol</th>
<th>Routine chest protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CTDIvol (mGy)</strong></td>
<td><strong>CTDIvol (mGy)</strong></td>
</tr>
<tr>
<td>≤ 61 Kg</td>
<td>62-90 Kg</td>
</tr>
<tr>
<td>DECT</td>
<td>SECT</td>
</tr>
<tr>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Comparison of radiation doses between DECT and SECT for both routine chest and pulmonary embolism (PE) protocols in different weight groups (≤ 61 Kg, 62-90 Kg, ≥ 91 Kg).

CTA with 50% reduced iodine dose (16 g)
The spectral acquisition was consecutively performed after routine contrast enhanced CT angiogram using 30 mL of 370 mg/ml iodine contrast.

Materials evaluated on GSI

Stone Composition & Treatment Decisions

Stone composition evaluated by measuring HU values
Kidney Stone Composition: Meta-analysis

- UA vs. Non UA stone differentiation in 734 stones
- 100% Sensitivity & 99.7% Accuracy

Gout diagnosis

DECT can help in the diagnosis of gout (articular deposition of Calcium Urate crystals).

International consensus Gout guidelines

CT Image Chain: Which step of Workflow does DECT affect?

1. Patient selection
   - CT scanning
   - PI scheduling
   - Scan acquisition

2. Image processing
   - Dual energy CT
   - Raw data
   - Low energy CT raw data
   - High energy CT raw data
   - Weighted average
   - Virtual non-contrast
   - Spectral curve

3. Image interpretation
   - Post-processing
   - Iodine (material density)
   - CT ordering
   - Pt scheduling
   - CT Image Chain: Which step of Workflow does DECT affect?

Team...

Radiology
- Specialty leaders
- Technologist
- Champion
- Specialty leaders
- Champion

IT
- Vendor
- Clinical Adoption of DECT
- Therapeutic Response Assessment
  - Iodine Concentration
  - Hemorrhage Vs Calcium
  - Hyperdense lesion Vs Solid lesion

Artifact Reduction
- Posterior fossa imaging
- Metal artifact reduction

Material Separation
- Renal stones composition analysis
- Liver fibrosis
- Fatty liver
- Gout
- Bone marrow edema
- Tendons
- Ventilation

Lesion Detection and Conspicuity
- Inflammatory lesions
- Malignancy
- Tumor staging
- Post-intervention (e.g., renal ablation, post-op)

Material Separation
- Contrast staining vs hemorrhage
- Calcification vs hemorrhage

Contrast Media Reduction
- Donor evaluation – liver and renal

Clinical Adoption of DECT

DECT protocols must be ideally used in patients <118kg (260lb) or transverse diameter <45cm for optimal image quality
Go slow... (start with key protocols)...

Current DECT protocols in different body regions at our institution:

- **Head & Neck Angiography**
  - Regular CM
  - Reduced CM
- **Pulmonary Angiography**
  - Regular CM
  - Reduced CM
- **Thoracic Aorta Angiography**
  - Regular CM
  - Reduced CM
- **Mesenteric Angiography**
- **Chest**
- **Head & Neck Angiography**
  - Brain
  - Kidney
  - Renal lesion
  - Urography
- **Donor Liver**
  - Renal
  - Pancreas
  - Oncology
  - Hypervascular lesion
  - Hypovascular lesion
  - Post ablation
- **Musculoskeletal**
  - Metal reduction
  - Enterography
  - Adrenal
- **Kidney**
- **Pancreas**
- **Oncology**
  - Hypervascular lesion
  - Hypovascular lesion
  - Post ablation
- **Musculoskeletal**
  - Metal reduction

**DECT Image Processing**

- **80/140 kV**
- **6-10 minutes**

Workstation generated on demand

Megibow A and Sahani DV. AJR 2012

**Course Design**

- Choosing the right platform
- Protocol development
- Image interpretation
- Images to transfer to PACS

**Image Interpretation**

- Demonstrate advantages of different protocols
- Demonstrate applications
- Demonstrate cases available for problem solving
- Demonstrate images for different applications
- Relevant case-specific non-routine reconstructions available for problem solving

**Workshop**

- Feedback to improve
Future Perspectives with DECT

**Workflow**
- Automation
- Scheduling
- Image transfer
- Post-processing
- Customized protocols

**Quantitation**
- Variance of HU across VMC images from all scanners
- Material quantitation accuracy across platforms
- Resolution
- Identification of additional materials (e.g., Fe, Cu, Zn)

**Safety**
- Further optimization of radiation dose
- Scanning
- Pediatric patients
- Ultra low-CAD protocols
- Bariatric DECT

**New technologies**
- Photon-counting CT
- New contrast media

**Summary**
- DECT has several potential applications in clinical care
  - For improved detection, characterization, staging and response assessment.
  - Material separation
  - Low iodine dose CTA
  - Artifact reduction
- The combination of low-kVp/keV series and iodine maps may allow better detection and characterization of primary and secondary lesions.
- Newer generation DECT technology overcomes few limitations
  - Better image quality
  - Lower dose
  - Permits heavier patient scanning
  - Desirable workflow

**Summary: Practice Pearls**
- Establishing a technologist-based workflow model is key
- Gradual adoption of DECT into existing CT practice
- Efforts to optimize workflow and protocols to meet sub-specialty practice demands
- Invest in education and software upgrades to enhance efficiency
Thank you...