Multi-energy CT: Extending the Power of Clinical CT

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Financial Disclosures

• Consultant, Bracco Diagnostics

Learning Objectives

• Types of DE scanners and comparative workflows

• Clinical Utilization
  – High Contrast Imaging
  – Material Decomposition

• Photon Counting CT

• DECT in Radiation Therapy
DECT is *not* a new idea

Determination of Atomic Number of Material

It is possible to use the machine for determining approximately the atomic number of the material within the slice. Two pictures are taken of the same slice, one at 100 kV and the other at 140 kV. If the scale of one picture is adjusted so that the values of normal tissue are the same on both pictures, then

Computerized transverse axial scanning (tomography): Part I Description of system

G. R. M. Housefield
Centre for Medical Sciences
University of London
(Shrewsbury, England, 1970 and in revised form, 1971)

5 configurations of commercial DECT

5 configurations of commercial DECT


Dual Source Dual Energy CT: Work Flow

NYU

Monoenergetic, Optimal Contrast, Multi KV;
Material Specific; Advanced
Pros and Cons of DE Approaches

<table>
<thead>
<tr>
<th></th>
<th>Fast kV switching</th>
<th>Dual-layer detector</th>
<th>Dual-source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simultaneous DE acquisition</td>
<td>Simultaneous DE acquisition</td>
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<td>Full dual-energy FOV</td>
</tr>
<tr>
<td>DE processing in both raw data and image domains</td>
<td>DE processing in both raw data and image domains</td>
<td>DE processing only in image domain due to 90° offset between tubes</td>
<td>No independent mA for high and low kV</td>
</tr>
<tr>
<td>Not enough power for low kV images</td>
<td>Not enough power for low kV images</td>
<td>2 tubes: More power for low kV images</td>
<td>Limited spectral separation</td>
</tr>
</tbody>
</table>
Dual Source Dual Energy Workflow - NYU

- Workflow
  - How we view DE image data
  - DE analysis-PACS interface
  - Image types available
Question 1

Which of the following statements concerning DECT acquisition is TRUE

A. All machines are calibrated such that there is no ability to vary high and low energy kVp

B. All scanners reconstruct images in projection space

C. High and low energy images may be blended in to create a final image that simulates a standard single energy 120 kVp CT image

D. DECT images cannot be acquired with isotropic voxels
Image viewing/archiving

What we Do

- 4mm axial/3mm coronal on PACS
  - Image interpretation
  - Long term Archive
- DE data
  - View PRN. Selected rendered images or series exported to PACS
  - A and B tube or Au/Sn thin sections sent to a long term archive from SCANNER

What we DON’T do

- We do NOT send A tube/B tube/mixed thin sections to PACS
- We do NOT routinely look at these images
- We do NOT routinely archive mono+, optimum contrast, low kV, VNC etc.

Clinical Uses of DE Acquisitions in Abdominal Imaging

- Improve Inherent Image Contrast
  - Low kV images
  - Optimal Contrast
  - Monoenergetic Imaging
- Precision CT numbers
  - Monoenergetic Imaging

- Material Decomposition
  - Calcium
  - Bone Removal
  - Iodine
  - VNC
- Reducing Radiation Dose
- Iodine Quantification

Improved Inherent Image Contrast
Using 80 kVp Image

- Iodine is more conspicuous
- Higher Noise level

Monoenergetic Imaging

- Improved image contrast
  - Greater Iodine conspicuity* than low kV image
  - "Salvaging CTA"
  - Lower IV contrast Dose
- Metal artifact reduction

*Dependent on setting
Monoenergetic Imaging

- 50 keV significant iodine visualization with acceptable noise
- 70 keV close to 100 kVp conventional CT
- >120 keV for metal artifact reduction
Question 2

• Concerning “monoenergetic” imaging, which of the following statements is FALSE

A. <50 keV images can help reduce the amount of administered IV contrast due to increased conspicuity of iodine
B. >100 keV images are useful for metal artifact reduction
C. Monoenergetic acquisitions have been shown to minimize pseudoenhancement of lesions
D. Hounsfield units are unchanged when comparing images at any monoenergetic setting.
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3-Material Decomposition

• Virtual Non contrast Imaging
  – Eliminating acquisitions
• Bone removal
• Characterization of renal calculi

Material Specific Decomposition(s)

• Native image composed of “3” materials
• Two are fixed, 1 variable
Material Specific Decomposition(s)

- Map the variable
  - Iodine Map

Material Specific Decomposition(s)

- Remove the variable
  - Virtual Non Contrast (VNC)

* Removal of iodine from the renal cortex

Courtesy: C. Leidecker, PhD, Siemens Medical Systems
Three Material Decomposition: Fat/Liver/Iodine

Quantifying: Fat, Liver, and Iodine

Courtesy: Tom O'Donnell, PhD
Clinical Utility of Material Specific Imaging
DSDE CT

• Bone Removal
• Calculi
• Virtual Non-Contrast Image
**Modified DE CT Urogram**

- **Indication**: Microscopic hematuria in patients under 40
- **Protocol**
  - Single pass CTU at 7 min following 200 cc IV contrast (240 mgI/ml)
  - VNC made from this single acquisition
- **Created WITH** input from urologists understanding that 2/3 calculi <3mm may be missed
Virtual Non-Contrast Image

- Respects well established paradigm of recognizing enhancement
  - Can get ROI values
- Iodine Map is equivalent method of acquiring same information
  - Can get quantification of enhancement and mg/I in tissue
- Eliminating acquisitions
2. Namburi et al. AJR 2010
VNC = 9.8
Mixed = 12.1

VNC = 39.6
Mixed = 57.2

VNC = 43.7
Mixed = 108.4

VNC = 43.7
Mixed = 108.4
Arterial/Portal Wash in Phase

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<th>Spleen</th>
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<tbody>
<tr>
<td>VNC</td>
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<td>49.0</td>
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<tr>
<td>CM</td>
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<td>35.4</td>
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<tr>
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Portal Venous Phase

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<th>Liver</th>
<th>Spleen</th>
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</thead>
<tbody>
<tr>
<td>VNC</td>
<td>56.0</td>
<td>50.5</td>
</tr>
<tr>
<td>CM</td>
<td>42</td>
<td>46.2</td>
</tr>
<tr>
<td>Mixed</td>
<td>98</td>
<td>96.7</td>
</tr>
</tbody>
</table>

Toepfer M. Eur J. Radiol: 2012
Attenuation on TNC and VNC with 3rd Generation DECT

Durieux P. et al. AJR 2018;210:1042-1058

Question 3

• Concerning virtual non-contrast images derived from DECT data, which of the following statements is true?

A. VNC Hounsfield unit (HU) values are reliably within 5 HU of true non-contrast (TNC) images

B. VNC HU are relatively independent of the amount of the iodine concentration in a given contrast enhanced ROI

C. VNC HU can be directly calculated from rapid kV switching DE scanners

D. VNC HU are less noisy than TNC images
Iodine Quantification

- Assessing tumor (neo)vascular “burden” before and during therapy
- Inflammation/repair in Crohn disease
Radiation Considerations

Conclusion: Dual Energy CT is feasible without additional dose. There is no significant difference in image noise, while CNR can be doubled with optimized dual energy CT reconstructions. A restriction in collimation is required for dose-neutrality at 140/80 kVp, whereas this is not necessary at 140 Sn/100 kVp. Thus, CT can be performed routinely in Dual Energy mode without additional dose or compromises in image quality.

Perceived Impediments to Routine Dual Energy Scanning

- Images are not as good
- Slows throughput in busy practice
- Too many images on PACS
  - Too much time to read
- Lack of workstation familiarity
- No “trust” in quantitative data
- Increased Radiation

Our Practice

- ~130 outpatient CASES per day on 2 machines,
  - Scanning hours 7:30 AM - 7 PM
- All Cr Abd/Pel, Chest and C-renal calculi studies on are done with DE
Photon Counting Multi-Energy CT

Following slides courtesy:
Shuai Leng, PhD. Mayo Rochester
Siemens Medical Solutions

Counting Detector Technology

- Semiconductor as direct X-ray converter
- Photoelectron creates electron-hole pairs
- Electrons induce short pulses on pads
- Pulses are counted individually with counter thresholds on different energy levels
- Multiple signals with spectral sensitivity

→ One scan yields multiple spectral datasets
• Enables “Multi-Energy Anytime”
  • Single-kVp Multi-Energy CT
  • Spectral information at full FOV
  • CT becomes quantitative modality
  • Three-material decomposition by K-edge imaging

• Opens Fields of New Clinical Research
  • Search of novel, photon counting specific CT applications

• Note: Quality of Two-Material Separation
  • Photon-Counting as good as kV-Switching
  • Photon-Counting does not outperform Dual-Source

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**Counting Technology: What is the Potential?**

• Further Dose or CM Saving Potential
  • More iodine contrast
  • Less image noise (better MTF)
  → Up to 46% more iodine CNR²
  (or 32% less dose or 20% less CM)

• “One-Stop Shop” Examinations?
  • Routinely perform scans at 140 kV
  • Same CNR as classical CT at 105 kV
  • Less scan protocols
  • Retrospective Multi-Energy analysis

• Note:
  • No significant boost of soft tissue contrast in native scans (e.g. grey-white matter)

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**Counting Technology: What is the Potential?**

• Beam-Hardening Artifact Reduction
  • Spectral information for refined artifact reduction

• High-Resolution CT Data
  • Significantly better spatial resolution in sub-pixel mode, approaching the spectral resolution of a conventional x-ray / DSA
  • Noise reduction in particular with sharp kernels
  • UHR modes at full dose usage

• Better IQ in Ultra-Low-Dose and Obese Scans
  • Less noise in low-signal scans → better IQ, less dose
  • Better stabilization of CT-values
  • Further suppression of streak artifacts
Counting Technology: What is the Potential?

- Single-kV Single-Scan Multi-Energy CT
  - Dual-Energy performance similar to Dual-Source CT
  - Multi-Energy to separate more than two materials

- Use well-established Dual-Energy Applications

- Explore novel Multi-Energy Applications:
  - Separate and quantify multiple contrast media?
  - Entirely new fields of clinical research?

Dual Energy CT in Radiation Therapy

Following slides courtesy:
Tom O’Donnell PhD
Siemens Healthineers USA

Tissue Characterization for Proton Therapy

Range uncertainty 3-4mm - BIG Problem
http://www.iba-protontherapy.com/why-proton-therapy
Attenuation Coefficient of an arbitrary material at a specific energy and a fixed density:

\[
\text{Attenuation of any material} = a_1 \text{ Compton Scatter (density)} + a_2 \text{ Photoelectric Effect (atomic number)}
\]

These are characteristic of the material

2 Equations and 2 unknowns:

<table>
<thead>
<tr>
<th>80kVp</th>
<th>140kVp</th>
</tr>
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<tbody>
<tr>
<td>\text{Compton Scatter on 80kVp scan}</td>
<td>\text{Compton Scatter on 140kVp scan}</td>
</tr>
<tr>
<td>\text{Photo Electric on 80kVp scan}</td>
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\[
\begin{align*}
\text{Attenuation on 80kVp scan} &= a_1 \text{ Compton Scatter on 80kVp scan} + a_2 \text{ Photo Electric on 80kVp scan} \\
\text{Attenuation on 140kVp scan} &= a_1 \text{ Compton Scatter on 140kVp scan} + a_2 \text{ Photo Electric on 140kVp scan}
\end{align*}
\]

\text{syngo.CT DE with Rho/Z*} \\
\text{TwinBeam Dual Energy}

Enables to calculate electron density and effective Z mass in one examination. 
Helps to differentiate and characterize different tissues in the body. 
Ideal for research oriented customers. 
PTI enables a novel way of calculating stopping power ratio (SPR) more precisely.

Courtesy of Universitätsklinikum Erlangen, Radiology Department. 
*TwinBeam postprocessing software is not approved. For usability in research only.
Interactive adjustment of material decomposition parameters for immediate optimization of the results with syngo.CT DE Rho/Z.

- Dual Spiral Dual Energy offers better accuracy
- Works where motion is limited
- TBDE will work in regions with excessive motion
- Reduced accuracy
- Not sure if it will let you exceed the SPR you achieve right now

Impediments to DECT for Routine Use in Therapy

- COST of Scanner
- Limited knowledge of how to process DE Data
- Proton Beam therapy has largest use
- Can be performed on ANY scanner
  - Shuttle mode DE
- Would require investment in software to process data