Objective

Understand technical implementations of multi-energy CT
  - How they work
  - Strengths and limitations

Content

4. Technical implementations of multi-energy CT
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    4.B.4. Dual-source acquisitions

Connections to Previous Presentations

Previous presentations
  - Introduction and Clinical Motivation (Dr. McCollough)
  - Physical Principles of Multi-energy CT (Dr. Flohr)

Multi-energy CT takes two or more CT images using different photon energies
  - Two key requirements for multi-energy CT imaging
    1. Simultaneously (ideally) – avoid motion artifacts
    2. Sufficient energy separation – improve image CNR
Detector-based methods:

4.A.1. Dual-layer detectors

- **Description:** Two layers of energy-integrating scintillator detectors
- **Commercial scanner:** iQon (Philips)
  - Top layer: low-density garnet scintillator
  - Bottom layer: GOS ($\text{Gd}_2\text{O}_2\text{S}$)

**Dual-Layer Detectors**

**Strengths**
- Absence of special protocols for dual-energy scanning
  - Every 120 and 140 kV scan provides both conventional images and dual-energy images
  - salvage studies with suboptimal contrast enhancement and artifacts
- Spatially and temporally aligned data
  - Projection-space decomposition
  - Anti-correlated noise removal
- No constraints on acquisition
  - Field of view
  - Rotation time
  - Tube current modulation

**Limitations**
- Only 120 and 140 kV are used for dual-energy imaging
  - 80 and 100 kV scans only generate conventional images
  - Detector layers: materials and thicknesses optimized only for 120 and 140 kV
- Energy separation
  - Smaller than two-kV methods
- Detector cross-talk between layers
  - Scattered photons in different pixels

**Photon-counting Detectors**

**Strengths**
- Similar to dual-layer detectors
- Optimal energy weighting
- Low electronic noise
- K-edge imaging
  - Adaptive energy bins
  - More than two beam materials
  - Multiple energy bins
  - Applications: multi-contrast agents imaging, new contrast agents

**Limitations**
- Research CT scanners
- Pile-up: incorrect photon energy and count
- Charge sharing and k-escape: reduce spatial resolution, incorrect photon count and energy, increase pile-up

**Energy integration**

\[
S_{\text{int}} = \frac{1}{E} \int E \cdot N(E) dE
\]

**Photon counting**

\[
S_{\text{count}} = \int 1 \cdot N(E) dE
\]

**Photon-counting Detectors**

- Optimal energy weighting
  - Example
    - Dual photons: 50 and 100 keV
    - Energy integrating: $0.5(50+100) = 75\%$
    - Photon counting: $1/(1+1) = 50\%$
- Low electronic noise
  - Signals below threshold are rejected.
4.B. Source-based methods

Consecutive volume or helical acquisitions with different tube potentials per rotation

**Strengths**
- Alignment of projection data
  - Projection space decomposition
- Each scan is similar to conventional scans

**Limitations**
- Motion misregistration and temporal alignment
  - As long as 500 msec to switch tube potential
  - Limits its use; not suitable for cardiac applications or rapid contrast concentration changes

4.B.2. Acquisitions with rapid tube potential switching

**Strengths**
- Tube current modulation is not available
- Finite switching time between low and high tube potentials – spectral separation

**Limitations**
- Tube current modulation is not available
- Finite switching time between low and high tube potentials – spectral separation

Technical challenges
1. Transition between low and high kVs: special tube and generator
2. Detector temporal response: Gemstone™ scintillator
Source-based methods:
4.B.3. Beam filtration techniques

- **Description:** the two halves of x-ray beam are filtered differently in the longitudinal direction
  - Half of detector rows used for the low energy beam and the other half for the high energy beam
  - Commercial scanners: SOMATOM edge and SOMATOM go (Siemens)
    - “Twinbeam”
    - 120 kV
    - High energy beam: 0.6 mm tin filter
    - Low energy beam: thin gold filter (k-edge 80.7 keV)

Source-based methods:
4.B.4. Dual-source acquisitions

- **Description:** Dual-source CT is a CT system with two measurement systems, i.e., two x-ray tubes and two corresponding detectors, offset within the gantry at an angle of about 90°
  - First commercial scanner: SOMATOM Definition (Siemens), 2006
  - Three generations: FOV of dual-energy imaging 26 cm → 33 cm → 35.6 cm

- **Scan parameters can be individually adjusted for both measurement systems**
  - Tube potential and current
- **Tube current modulation**
- **Optimized spectral separation:** additional prefiltration into the high-energy beam

- **Strengths**
  - Smaller central scan field of view for dual-energy imaging
  - Image-space decomposition
  - Cross-scattered radiation

- **Limitations**
  - Spectrum separation smaller than two-kV method
  - Powerful generator: strong filtration
  - Pitch up to 0.5
Summary

- Each implementation has unique strengths and limitations.
  - Some limitations may be overcome by future technology advancement.
- Strengths and limitations discussed in the report may not be directly translated to clinical performance.
  - Literature and user experiences.
  - Clinical applications and dosimetry consideration (next presentation by Dr. McCollough).

Thank you!