Pitfalls and Remedies of MDCT Scanners as Quantitative Instruments

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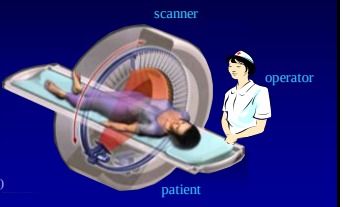
1

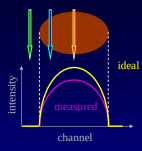
Root-Causes of CT Number Inaccuracies

- **Nature of the X-ray Physics**
  - Beam Hardening
  - Scatter
  - Aliasing
- **New Technology**
  - Helical
  - Cone Beam
  - Incomplete Sampling
- **Patient**
  - Motion
  - Photon Starvation
- **Operator**
  - Protocols (scan thin, recon thick)
  - Partial Volume



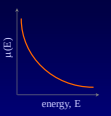
2

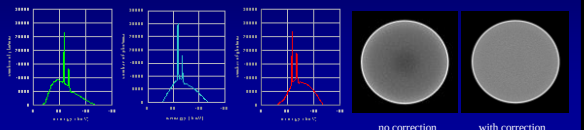
Nature of Physics: Beam Hardening



- poly-energetic x-ray photon
- energy-dependent μ(E)
- measured projection error
- polynomial correction

$$p' = \sum_{n=1}^{N} \alpha_n p^n$$





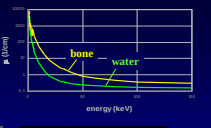
0 cm water | 15 cm water | 30 cm water

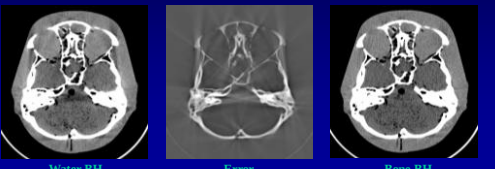
no correction | with correction

3

Bone Beam Hardening

- The attenuation characteristics of bone is significantly different from that of soft tissue.
- Similar observation can be made for contrast agents.



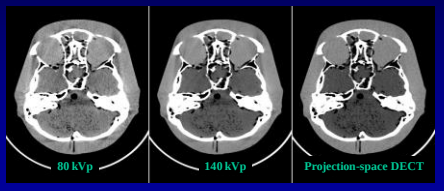


Water BH | Error | Bone BH

4

Dual Energy Correction

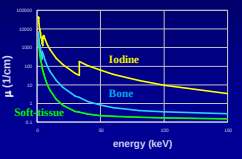
- Dual energy takes advantage of the two types of x-ray interaction with matter: photoelectric and Compton.
- Use of the additional information can effectively remove BH.



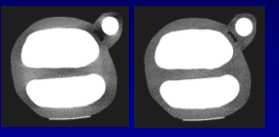
ww=300 5

Impact of Iodine Contrast

- Iodine contrast
  - Cardiac phantom experiments
  - Dual energy solution



Conventional 120kVp Dual Energy 70keV



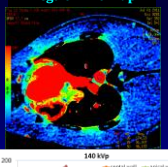
Cardiac Phantom

6

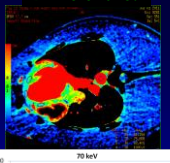
Perfusion

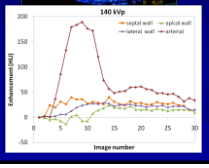
- Perfusion is important to test the viability of a tissue
- Perfusion requires accurate quantitation of CT numbers
- BH is one of the major sources of error

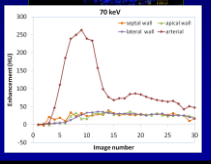
Regular 140 kVp



DE Mono 70 keV







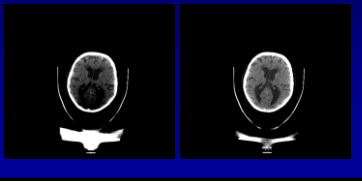
Images courtesy of Drs. T. Lee and A. So of St. Mary's Hospital, London, OT, Canada

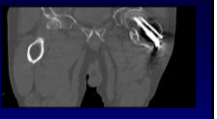
7

Metal-induced Error

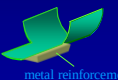
- CT is sensitive to the presence of high-density and high-frequency objects.
- Special care must be taken to avoid placing foreign objects inside the scanner FOV.

0.625mm thickness, 1.0mm apart





140kVp

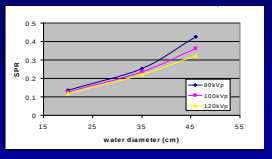


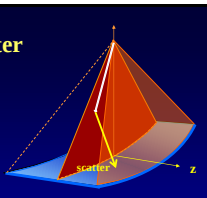
metal reinforcement

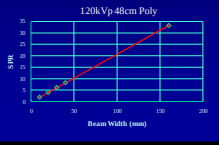
8

Nature of Physics: Scatter

- Scatter-to-Primary Ratio (SPR) increases almost linearly with the z-coverage.
- SPR decreases with the increase in kVp
- SPR increases with the object size



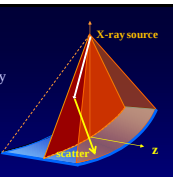


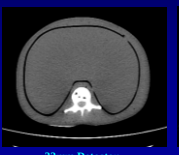


9

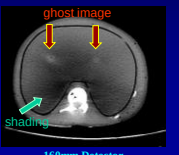
Scatter Artifacts

- Scatter-to-Primary Ratio (SPR) increases almost linearly with the z-coverage.
- SPR decreases with the increase in kVp
- SPR increases with the object size





32mm Detector



160mm Detector

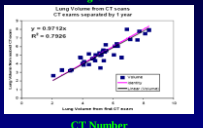
10

Lung CT Number Accuracy

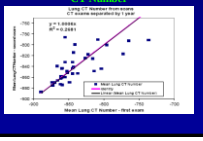
- **Inspiration Level**
- **Beam Hardening**
  - **Patient centering**
  - **Variation of object size**
  - **Presence of non-water materials**
- **Scatter**
  - **Increased volume coverage**
  - **Insufficient post-patient collimation**

JP Sieren, PF Judy, DA Lynch, JD Newell, HO Coxson, and EA Hoffman, "QIBA Quantitative CT: Towards routine quantitative CT in obstructive lung disease," QIBA COPD/Asthma Subcommittee

Lung Volume



CT Number

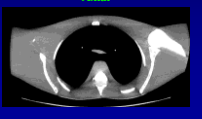


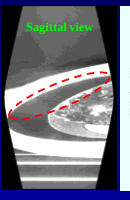
11

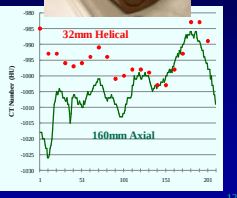
Air-Lung Accuracy

- Air CT number can be impacted by
  - Increased cone beam effect
  - Increased scatter

Axial





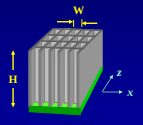


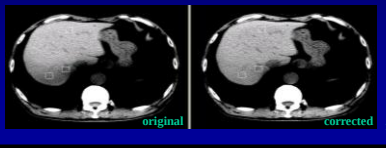
12

Scatter Correction

- Increased collimator aspect ratio: H/W
- 2D collimation
- Algorithmic correction possible
- Phantom calibration

COPDGene Phantom (CTP657)



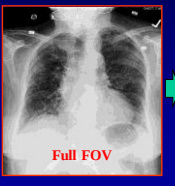


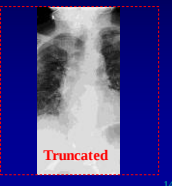
13

Truncation Issue

Chest X-ray

- For x-ray radiography, truncation does not cause artifact inside FOV.
- Truncated projection will cause significant artifacts for CT





14

Size Matters

- CT is sensitive to both high density object and objects extended outside the FOV.
- Patient arms need to be positioned outside the FOV.

CT Image

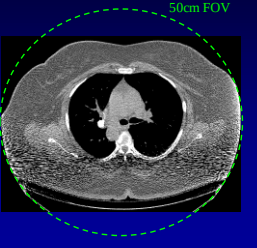
15

Photon Starvation

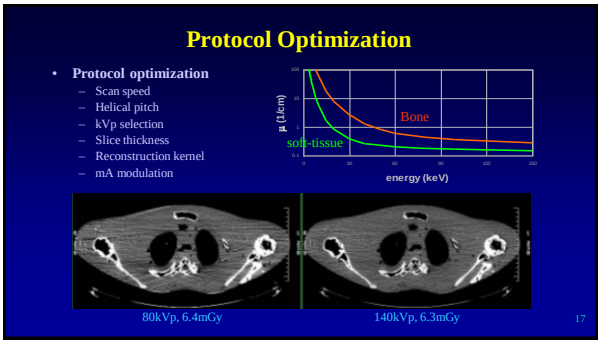
- Beer's law indicate that the amount of attenuation increases exponentially with path length.

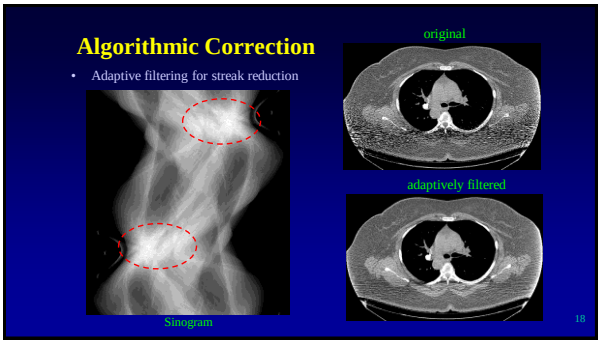
$$\frac{I}{I_0} = e^{-\mu L}$$

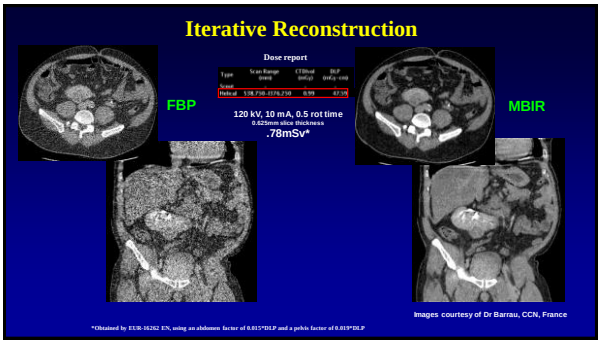
- At low signal level, the noise in the projection is no longer dominated by the x-ray photon.
- Convolution filtering operation will further amplify the noise and streak artifacts will result.

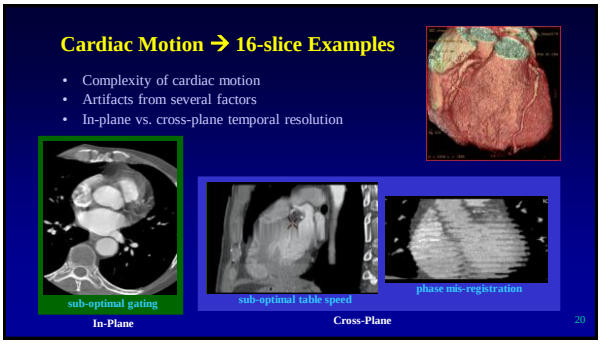


16


Protocol Optimization
Protocol optimization
Scan speed
Helical pitch
kVp selection
Slice thickness
Reconstruction kernel
mA modulation
μ (1/cm)
Bone
soft-tissue
energy (keV)
80kVp, 6.4mGy
140kVp, 6.3mGy
17

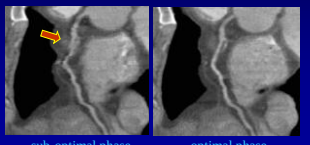

Algorithmic Correction
Adaptive filtering for streak reduction
original
adaptively filtered
Sinogram
18


Iterative Reconstruction
Dose report
FBP
MBIR
120 kV, 10 mA, 0.5 rot time
0.625mm slice thickness
.78mSv*
Images courtesy of Dr Barrau, CCN, France
*Obtained by EUR-16262 EN, using an abdomen factor of 0.015*DLP and a pelvis factor of 0.019*DLP

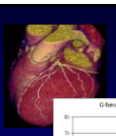

Cardiac Motion → 16-slice Examples
Complexity of cardiac motion
Artifacts from several factors
In-plane vs. cross-plane temporal resolution
sub-optimal gating
In-Plane
sub-optimal table speed
phase mis-registration
Cross-Plane
20

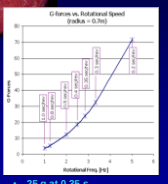
Artifact Correction

- In-Plane Temporal Resolution Improvement:
  - Phase optimization
  - Faster scan speed
  - Multiple source-detector
  - Advanced reconstruction



sub-optimal phase optimal phase



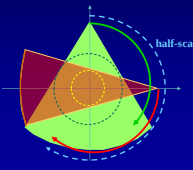


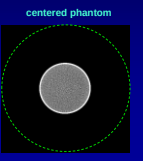
- 25 g at 0.35 s
- 8X safety margin → 200 g
- 76 g at 0.2 s
- 8X safety margin → 612 g

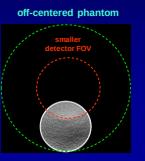
21

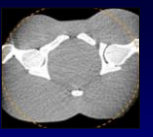
Advanced Technology-induced Artifact

- Half-scan: π + fan angle acquisition.
- Dual source reduces the acquisition by 40-45%
- Two detectors have different size
- Object outside small FOV may cause artifacts.
- Compensation algorithm can reduce the impact





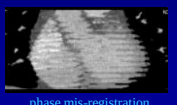




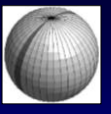
22

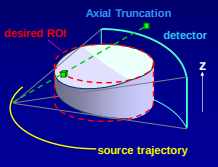
Cross-Plane Temporal Resolution: Cone Beam CT

- Increase z-coverage will reduce phase mis-registration artifacts.
- Entire heart covered by a single rotation.
- Step-and-shoot mode artifacts are due to:
  - Missing frequencies
  - Mis-handled frequencies
  - Z-truncation



phase mis-registration





23

Cone Beam Axial

- Exact cone-beam reconstruction does not exist.
- Large cone angle can lead to cone-beam artifact.

Small Detector
Helical Mode

Large Detector
Step-and-shoot

ww=600

24

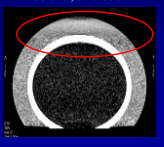
Cone Beam Axial

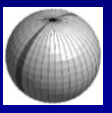
- Exact cone-beam reconstruction does not exist for step-and-shoot mode.
- Large cone angle can lead to cone-beam artifact.
- Active research in on-going

Axial, Phantom

Axial, Phantom

Coronal, Simulation

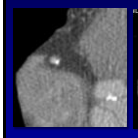




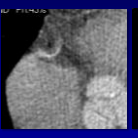
25

Temporal Resolution Improvement: Advanced Reconstruction Algorithms

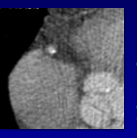
- Characterize cardiac motion
- Compensate for motion



Conventional Rest/Low HR



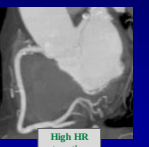
Conventional Stress/High HR



Advanced Stress/High HR

Conventional

Advanced



High HR + motion correction

26

Conclusion

- There are many sources of error for quantitative CT
  - Nature of Physics
  - New Technologies
  - Patient
  - Operator
- Many approaches are taken to reduce or eliminate the error.
- It takes a combined efforts from manufactures, CT operators, and patient corporation to reduce the impact of these pitfalls to a minimum.

27

28