IMAGE RECONSTRUCTION AND ARTIFACT REDUCTION

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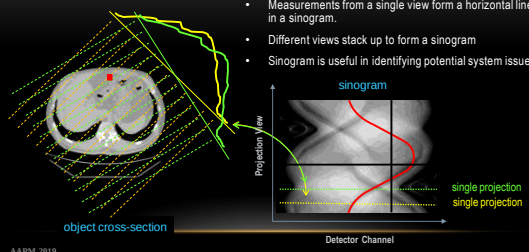
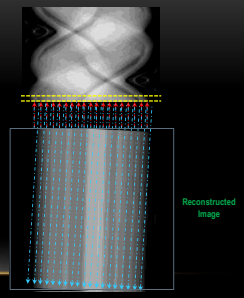
SINOGRAM

- Measurements from a single view form a horizontal line in a sinogram.
- Different views stack up to form a sinogram
- Sinogram is useful in identifying potential system issues



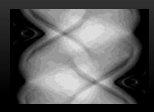
INTUITIVE RECONSTRUCTION

- Each measurement in the sinogram is generated by x-ray attenuated along a line
- Every point along the path has equal probability of contributing to the measurement
- The entire path is "painted" evenly with the measured intensity
- The process is repeated for all views with overlay
- This process is called "backprojection"

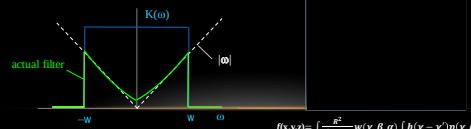


Filtered Backprojection

- Blurry effect can be compensated for by "deconvolution" in either image or sinogram
- Sinogram "deconvolution" is a ramp shaped filter in frequency domain
- Combined with backprojection, the process is called "filtered backprojection"



Original Sinogram

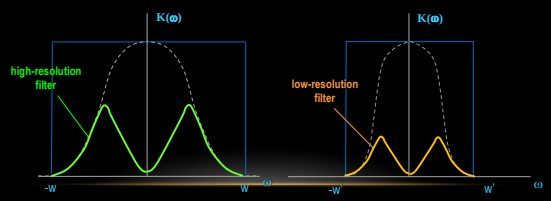


Reconstructed Image

$$f(x,y,z)=\int \frac{\pi^2}{L^2(x,y,\beta)} w(\gamma,\beta,\alpha)\int h(\gamma-\gamma')p(\gamma,\beta,\alpha)d\gamma d\beta$$

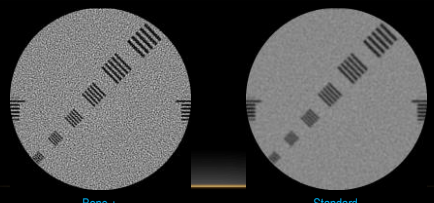
Filter Implementation

- Rectangular window can be modified to shape the frequency response.
- Different cutoff frequencies to create different reconstruction kernels.



Recon Filter Impact

- Higher frequency generally lead to sharper but noisier image
- For FBP, there is a tradeoff between spatial resolution and noise

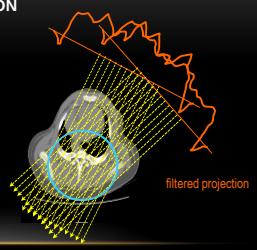


Bone +

Standard

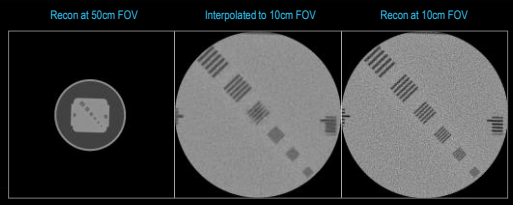
Targeted Reconstruction

- Clinical interests sometimes focus only on a small region inside the object
- If the ROI is smaller than scan FOV, backprojection can be performed over a portion of the filtered projection to form a targeted reconstruction.

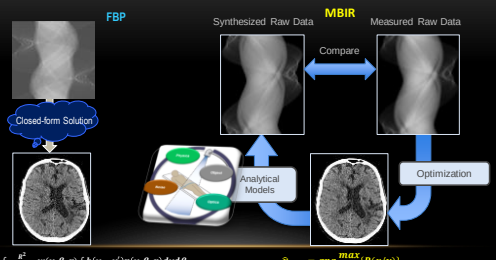


Targeted Reconstruction

- Image pixel size changes linearly on the reconstruction FOV.
- Targeted reconstruction can result in better spatial resolution.

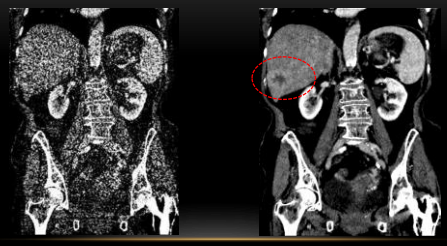


Model-based Iterative Reconstruction (MBIR)



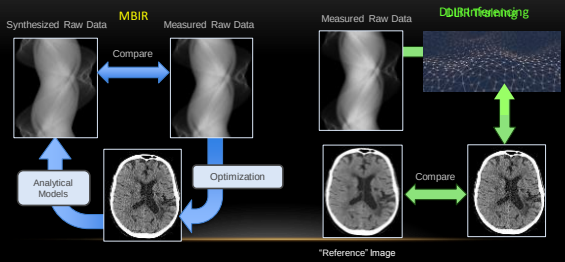
Clinical Example

Oncology abdomen/pelvis 0.61mSv*

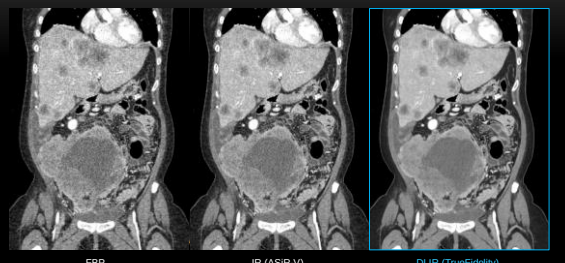


FBP MBIR (Veo)

Deep Learning Image Reconstruction



Reconstruction Comparison



FBP IR (ASiR-V) DLIR (TrueFidelity)

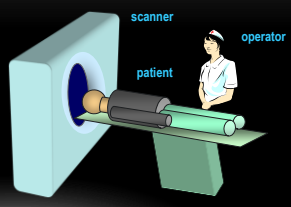
Extended FOV Reconstruction FOV

- For RT applications, desired FOV is larger than the detector SFOV
- Conventional technology often fails to produce accurate patient skin line
- DL-based algorithm can improve the outcome

Conventional Extended FOV DL-based Extended FOV

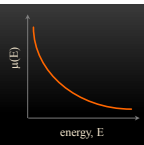
Image Artifacts

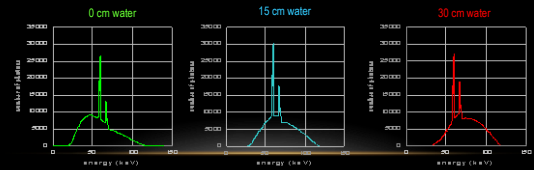
- Nature of the X-ray Physics
  - Beam Hardening
  - Scatter
  - …
- Limitations of CT Technology
  - Helical
  - Cone Beam
  - …
- Patient-induced
  - Motion
  - Photon Starvation
  - …
- Operator-induced
  - Suboptimal protocols
  - Patient positioning
  - …



Nature of Physics: Beam Hardening

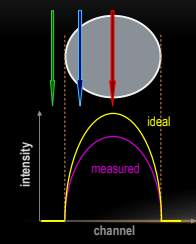
- X-ray photons in CT are poly-energetic.
- The attenuation, μ(E), is energy-dependent.
- The path length changes in objects
- The measured projection is not line integral of μ.



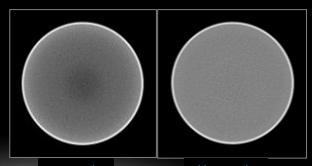


Water Beam Hardening Correction

- Water beam hardening can be corrected with polynomial expansion of the projections.

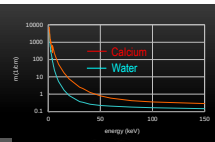


$$p' = \sum_{n=1}^{N} \alpha_n p^n$$



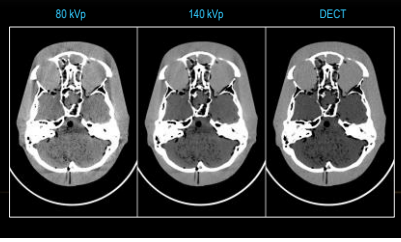
Bone Beam Hardening

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



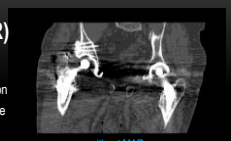
Dual Energy Correction

- Dual energy scans the object with two different kVps.
- Use of projection-space material decomposition can effectively remove BH

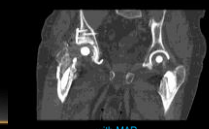


Metal Artifact Reduction (MAR)

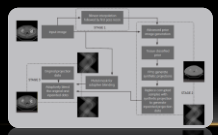
- Metal inside patient body is a major source of artifact
- Metal objects induce beam-hardening and photon starvation
- MAR algorithm is an iterative correction approach to restore soft-tissue in the image



without MAR

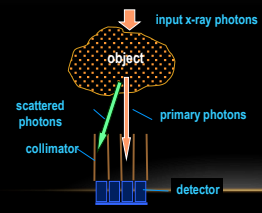


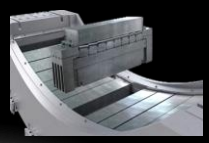
with MAR



Scatter

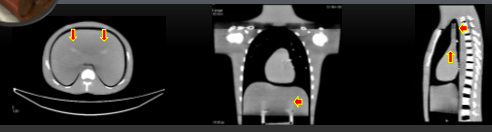
- Scatter increases with exposure volume.
- Post patient collimator can be used effectively to reject the scatter.
- A small portion of the scattered radiation can reach the detector.





Phantom Test

160mm System with 1D Collimator



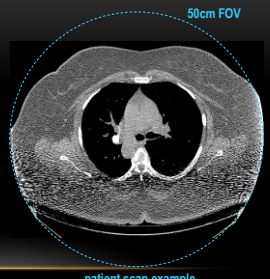
160mm System with Focusing 2D Collimator

Photon Starvation

- The amount of attenuation increases exponentially with path length.

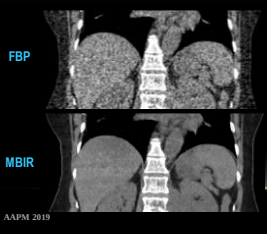
$$\frac{I}{I_0} = e^{-\mu L}$$

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



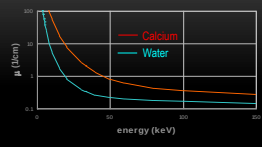
Artifact Reduction

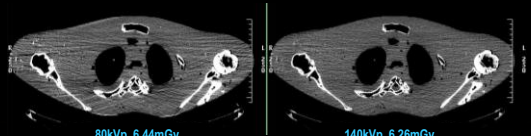
Algorithmic Correction
- Adaptive filtering for streak reduction
- Iterative reconstruction



Protocol Optimization

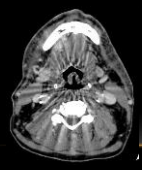
- Scan speed
- Helical pitch
- kVp selection
- Slice thickness
- Reconstruction kernel
- mA modulation

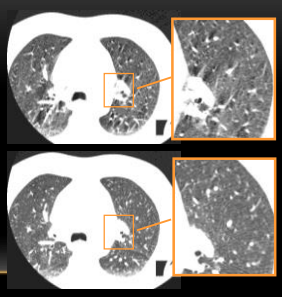




Voluntary Motion

- Better patient training
- Better instruction
- Faster scan speed
- Advanced algorithm





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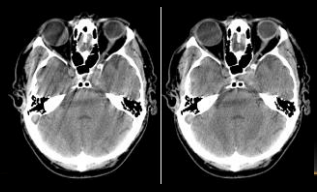
Operator-Induced

- CT operator plays an important role in artifact reduction.
- Improperly secured patient can lead to motion artifact.



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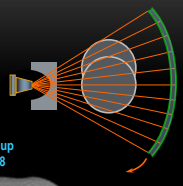
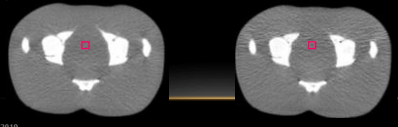
Patient Centering

- Bowtie filter is employed in most scanners.
- It assumes centered oval shaped objects.
- Patient centering is important.

centered
σ=28.8

10cm up
σ=53.8





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WIDE-CONE: MATHEMATICAL CHALLENGE

- Axial wide-cone reconstruction faces three major technical challenges:
  - missing frequency (axial mode sampling pattern)
  - z-truncation (cone-beam geometry)
  - redundant data handling (half-scan to improve temporal resolution)
- Solution to these challenges requires extensive research and testing.

Missing Frequency — Z-truncation — Redundant Data Mishandling

ALGORITHM COMPARISON

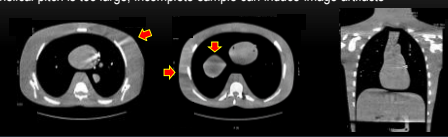
Traditional Reconstruction

Advanced Reconstruction

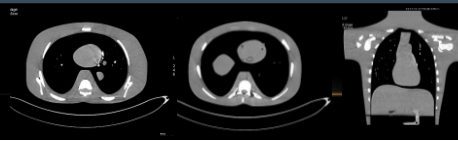
HIGH HELICAL PITCH IMPACT

- When helical pitch is too large, incomplete sample can induce image artifacts

Pitch 3.2



Pitch 1.2



SUMMARY

- Three generations of reconstruction algorithm
  - Filtered backprojection (FBP)
  - Iterative reconstruction (IR)
  - Deep-learning image reconstruction (DLIR)
- Many sources of CT artifacts
  - Nature of Physics
  - New Technologies
  - Patient
  - Operator
- It takes a combined efforts from manufactures, CT operators, and patients to obtain the best image quality.