Image Reconstruction Principle & Recent Techniques in PET/CT

서울대학교병원 : 도용호

Overview

1. **PET**
   1) Positron Emission & Annihilation
   2) 2D & 3D Acquisition
   3) Reconstruction Methods
      - FBP, MLEM, OSEM
      - Point Spread Function
   4) Time of Flight

2. **CT**
   1) Automatic Exposure Control
   2) Optimized Selection of X-ray Tube Voltage
   3) Iterative Statistical CT Reconstruction

PET Parameters for ^{18}F-FDG Torso

Acquisition Type	**3D Acquisition**	
Emission Time	**1min/bed**	
Reconstruction Method	**UltraHD-PET(OSEM3D+PSF+TOF)**	
Reconstruction Parameters	Iteration / Subsets	2 / 21
	Image Size	200
	Zoom	1.0
	Gaussian Filter	5.0 mm

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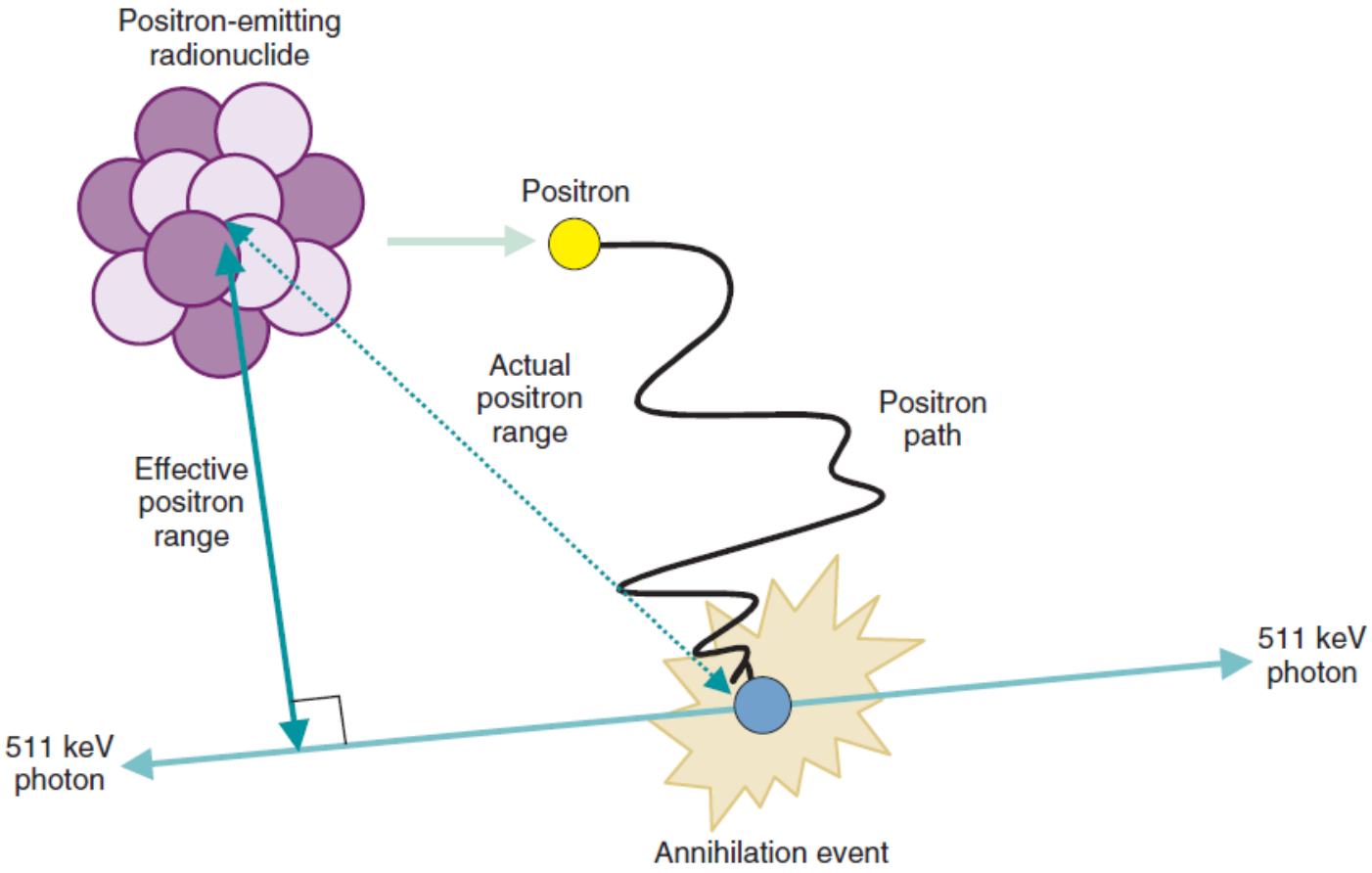
Positron Emission & Annihilation

Positron Emission & Annihilation



* **Life time of e^+:** 10^{-10} sec

* **Mass energy of e^+ & e^- :** 511keV ($E=mc^2$)

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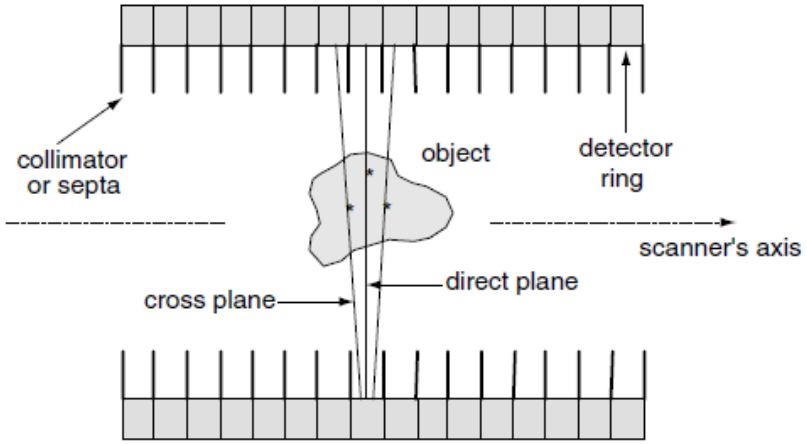
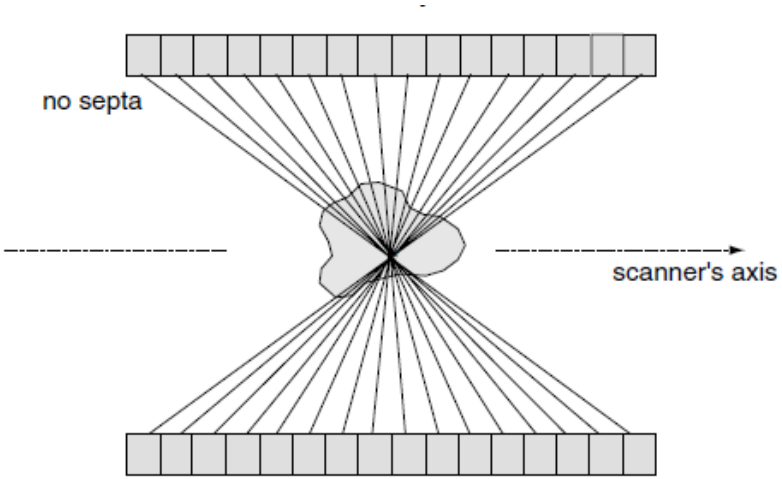
2D and 3D Acquisition

2D vs 3D Acquisition



2D mode with septa



3D mode with no septa

Features of fully 3D mode

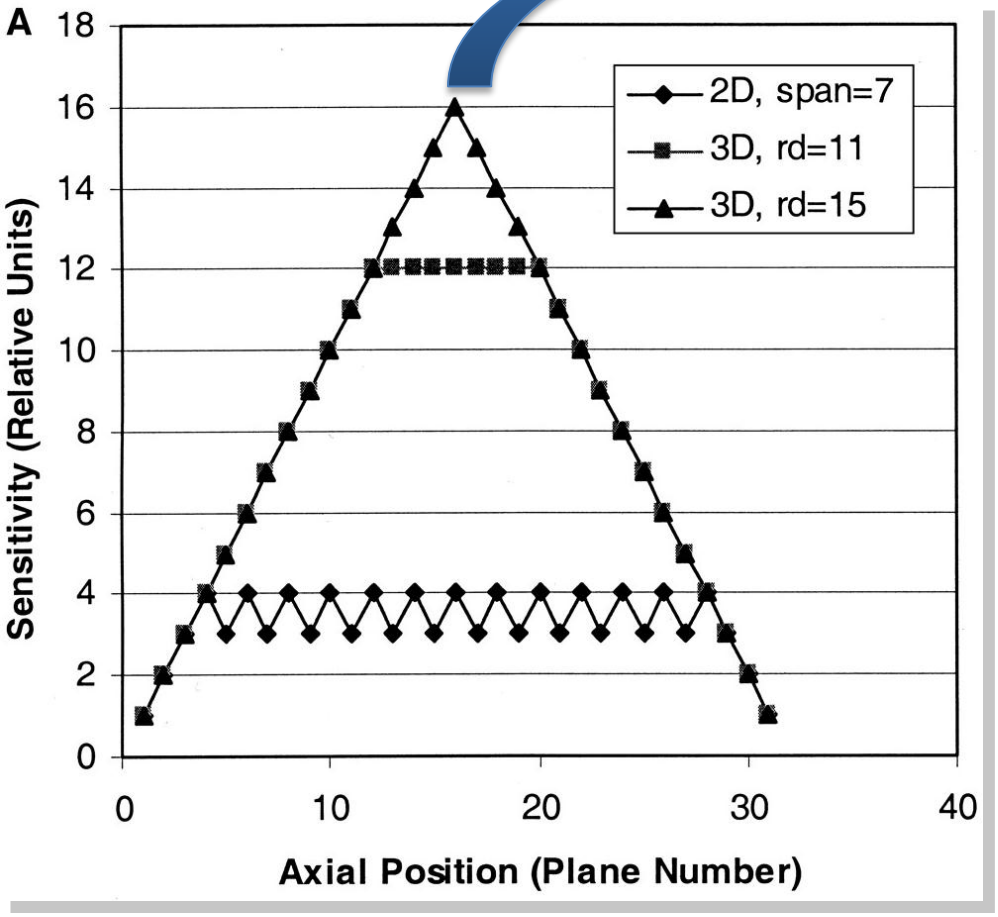
- Pros

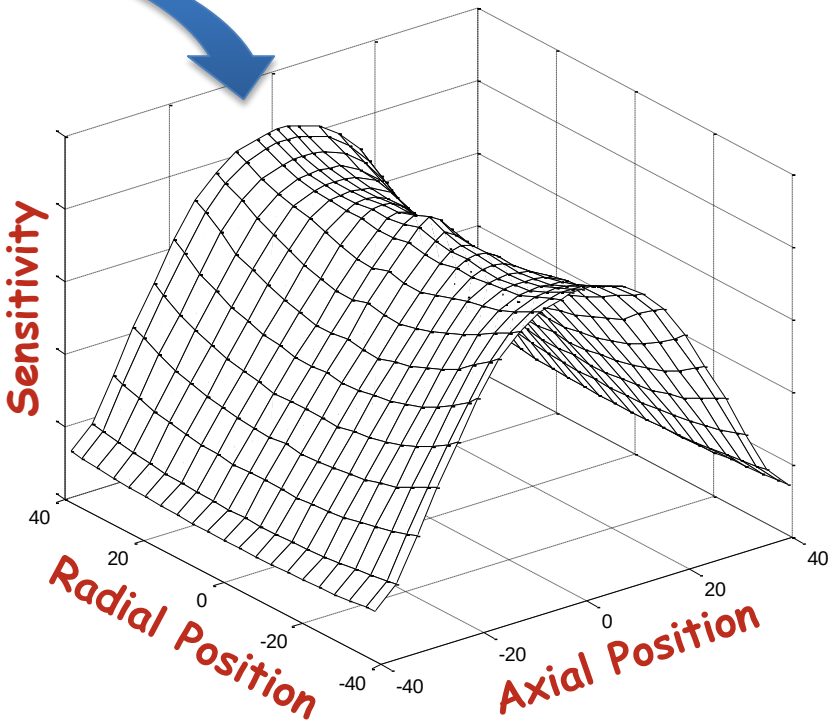
1. Higher efficiency
2. Lower does required
3. Shorter scan times
4. Higher count rate

- Cons

1. Higher scatter
2. Data increasing
3. Recon algorithm is complicated and time consuming

Sensitivity of 3D Acquisition





*Beds need to be overlapped to produce uniform image
Overlap of mCT is **48%**

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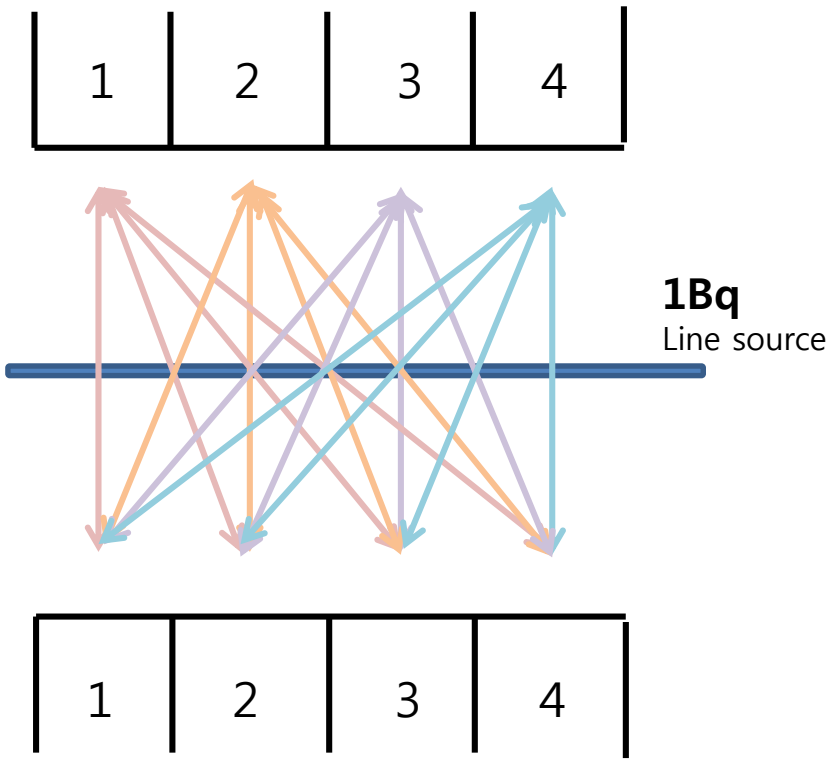
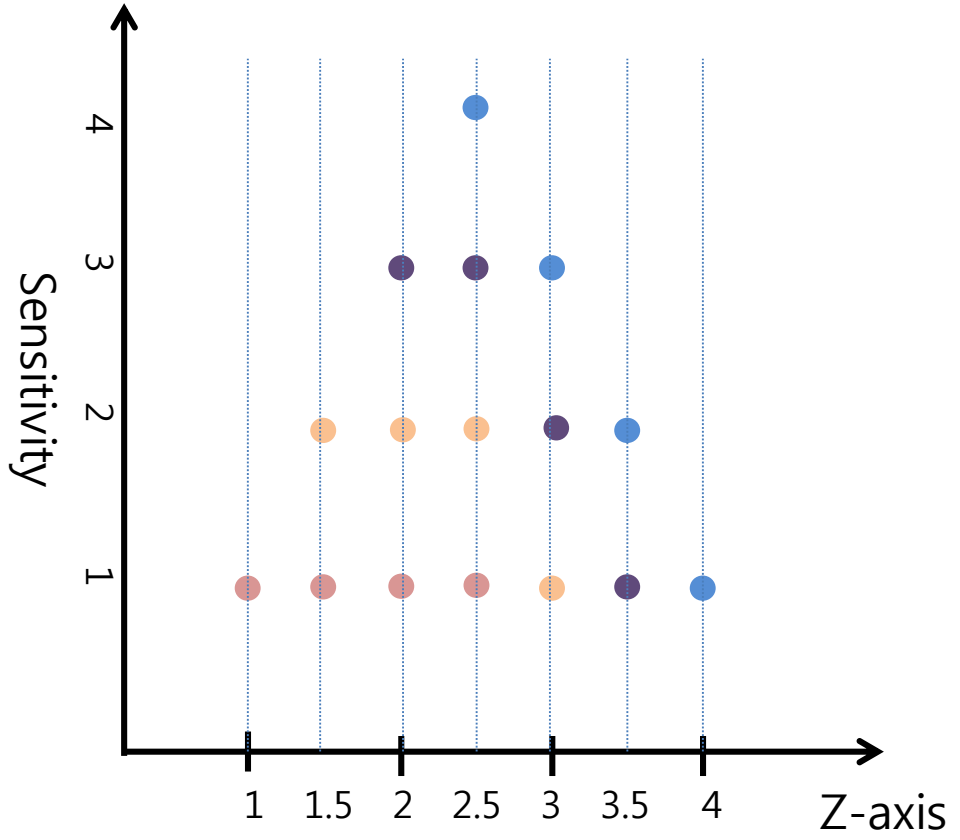
Z-axis Overlap – Full 3D mode





Z-axis Overlap

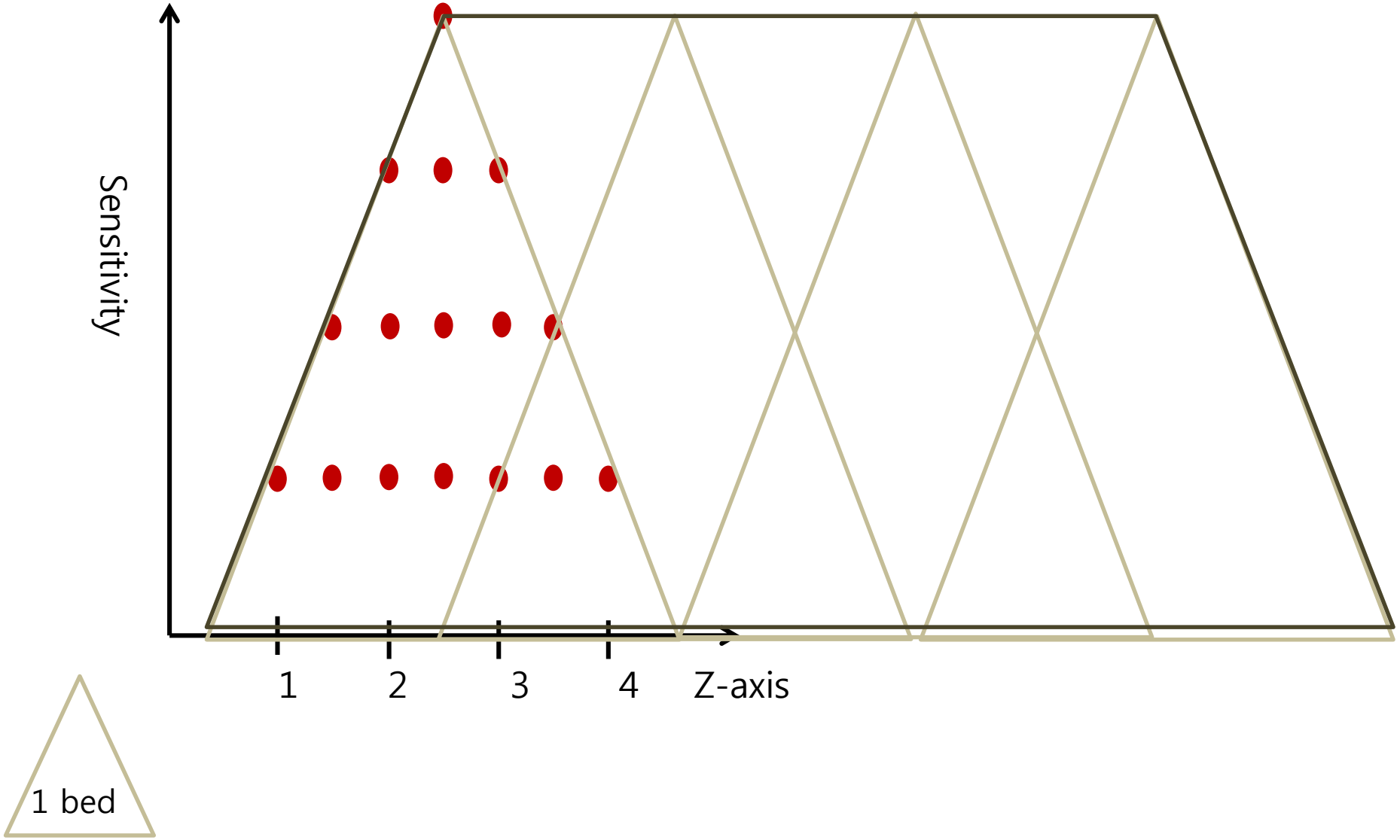


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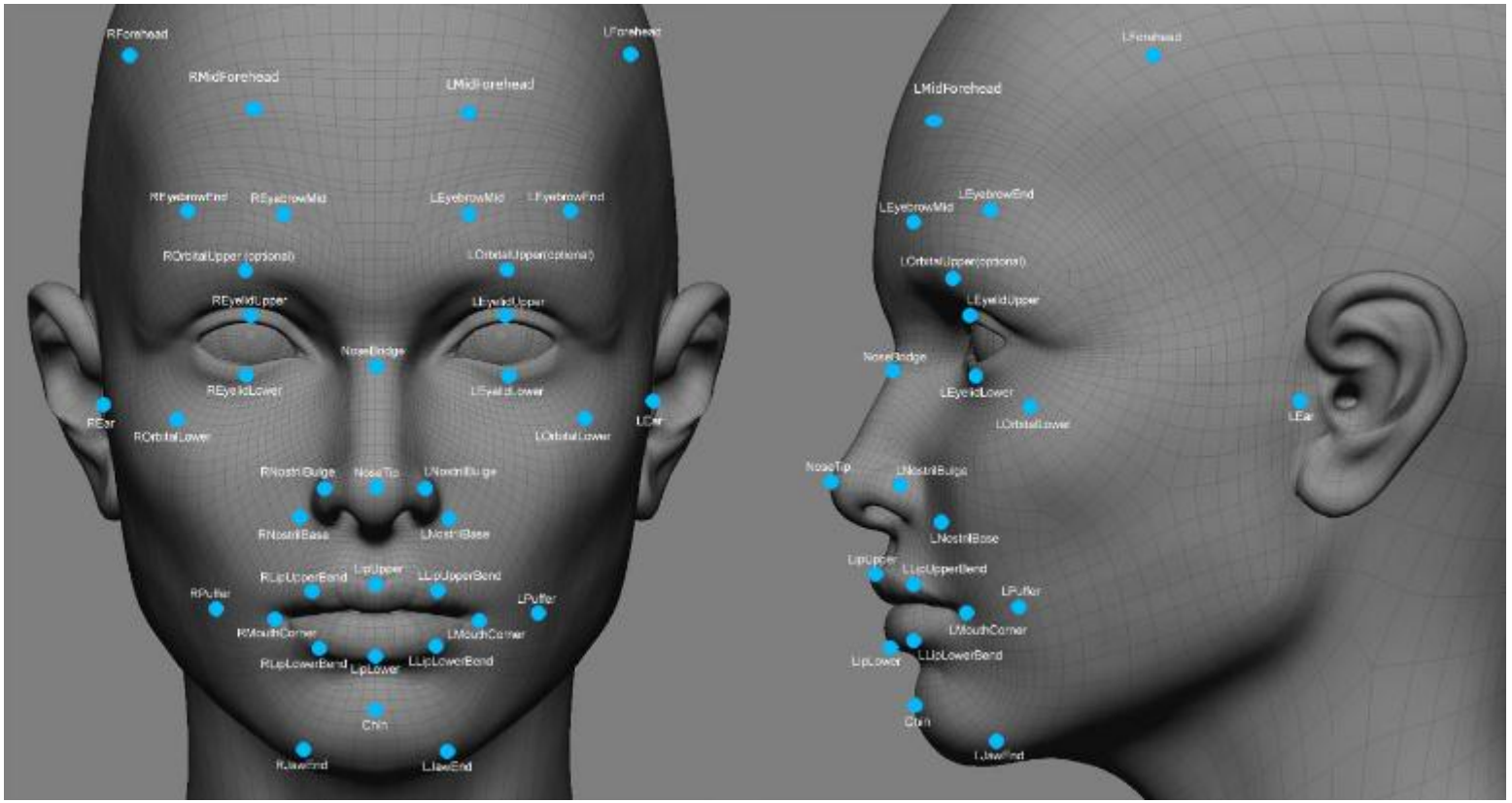
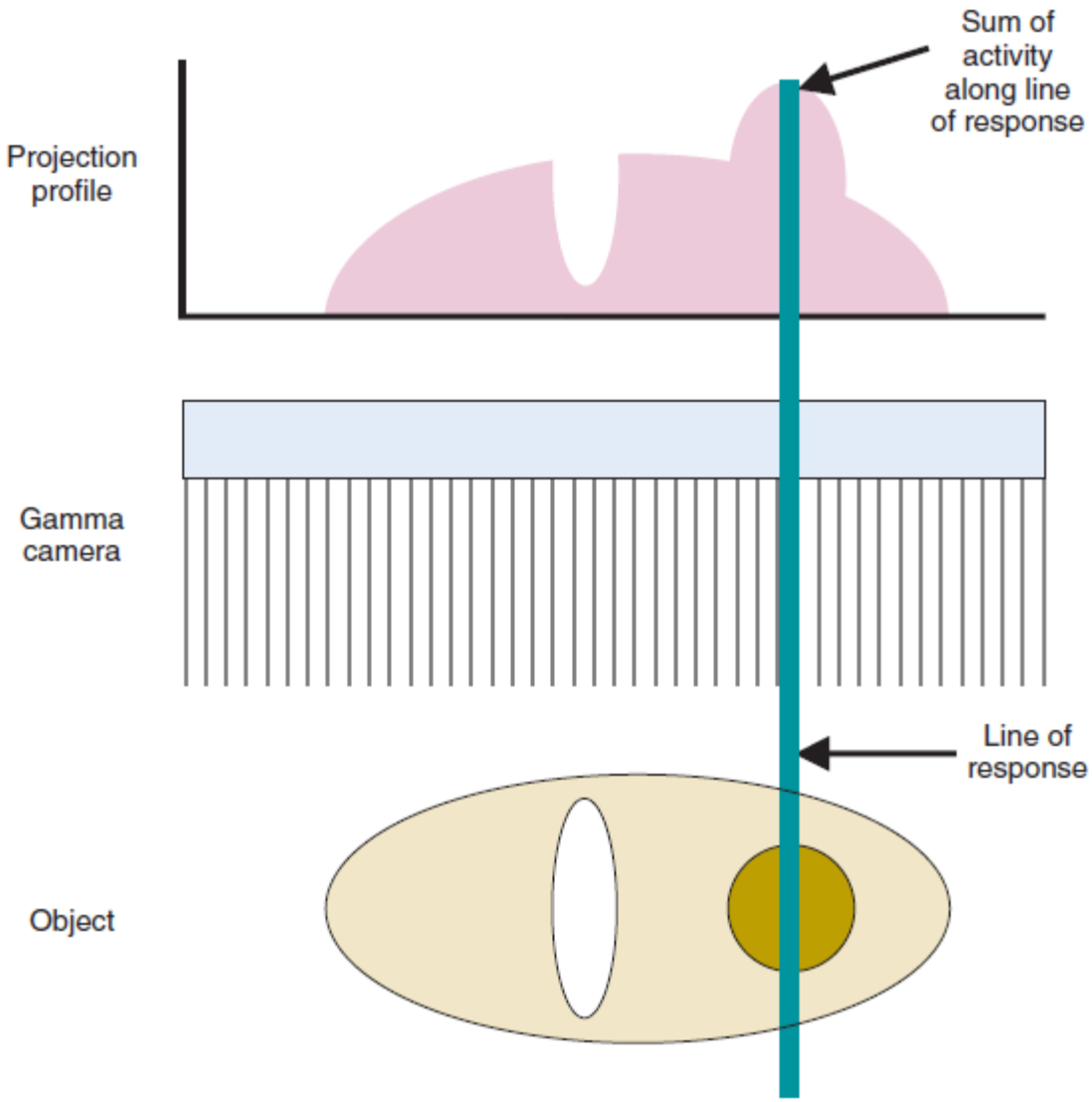
Image Reconstruction

Tomography

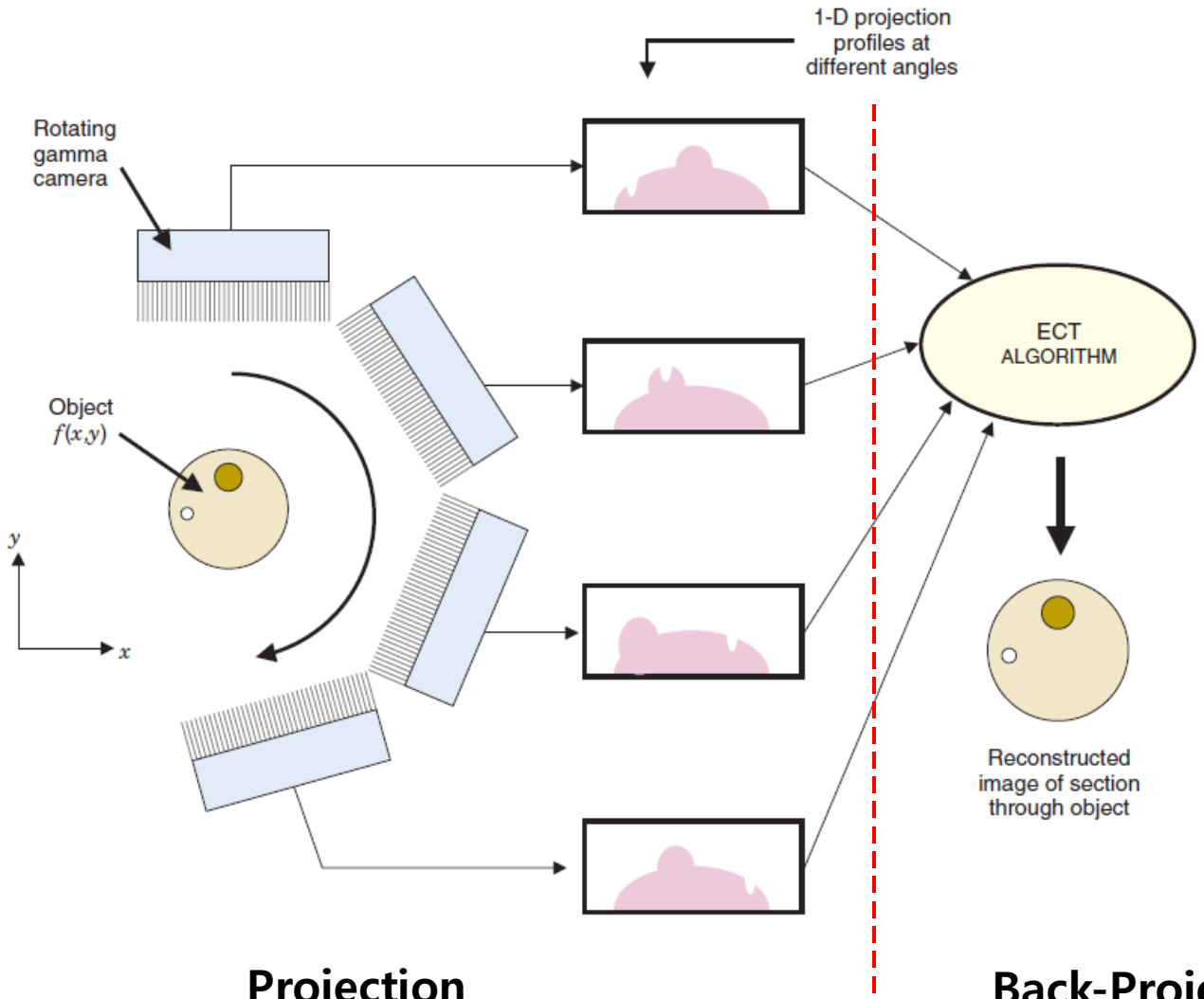

RForehead
LForehead
RMidForehead
LMidForehead
REyebrowEnd
REyebrowMid
LEyebrowMid
LEyebrowEnd
ROrbitalUpper (optional)
LOrbitalUpper(optional)
REyelidUpper
LEyelidUpper
NoseBridge
REyelidLower
LEyelidLower
REar
LEar
ROrbitalLower
LOrbitalLower
RNostrilBulge
NoseTip
LNostrilBulge
RNostrilBase
LNostrilBase
RLipUpperBend
LipUpper
LLipUpperBend
RPuffer
LPuffer
RMouthCorner
LMouthCorner
RLipLowerBend
LipLower
LLipLowerBend
Chin
RJawEnd
LJawEnd
LMidForehead
LEyebrowMid
LEyebrowEnd
LOrbitalUpper(optional)
LEyelidUpper
NoseBridge
LEyelidLower
LOrbitalLower
LEar
NoseTip
LNostrilBulge
LNostrilBase
LipUpper
LLipUpperBend
LPuffer
LMouthCorner
LipLower
LLipLowerBend
Chin
LJawEnd

Projection



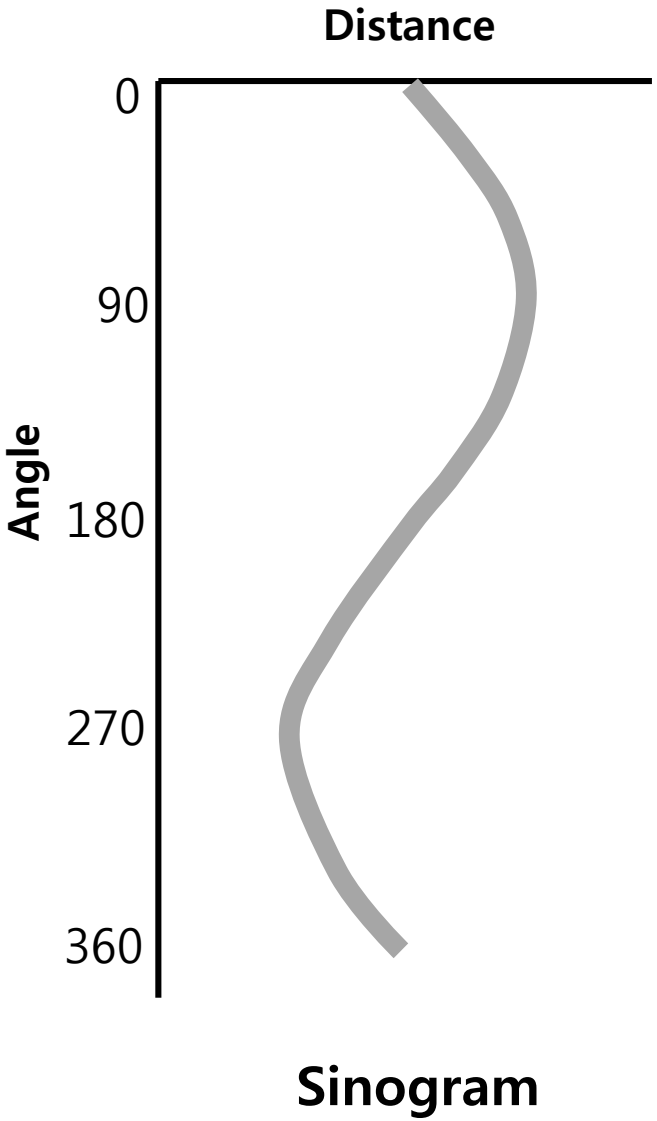
"Physics in Nuclear Medicine"

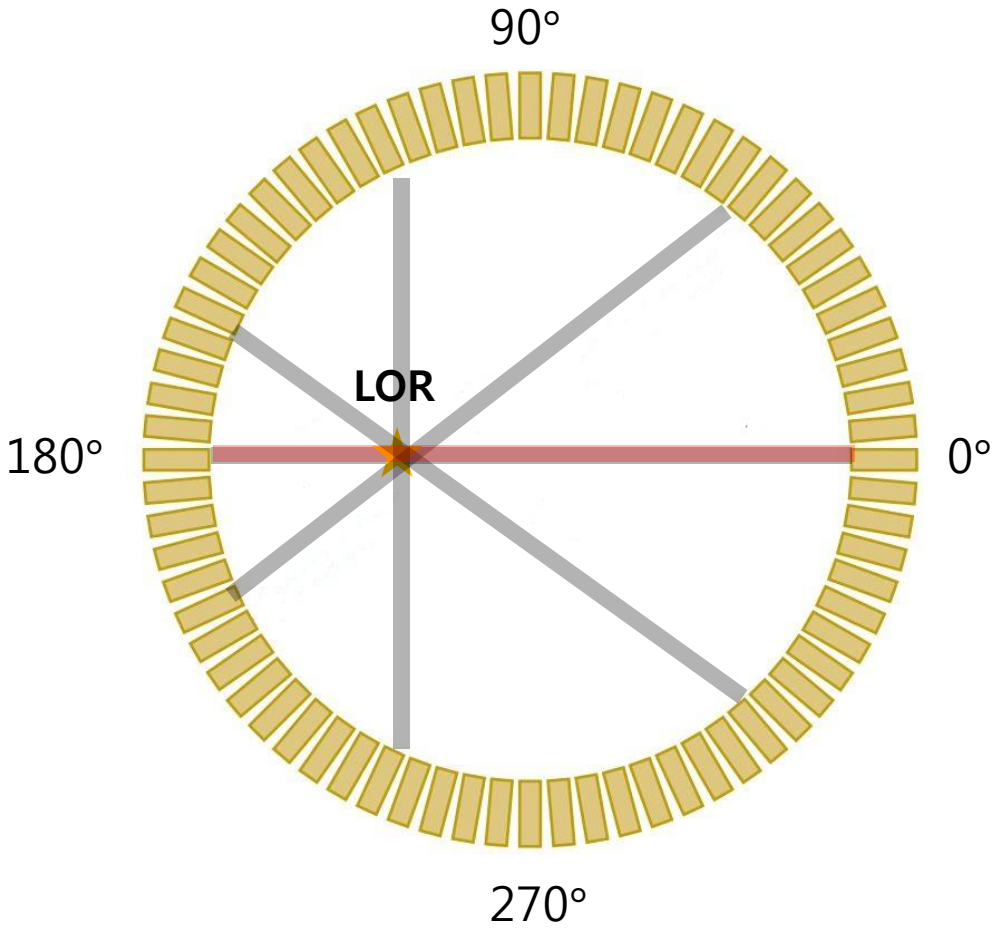
Projection & Back-projection



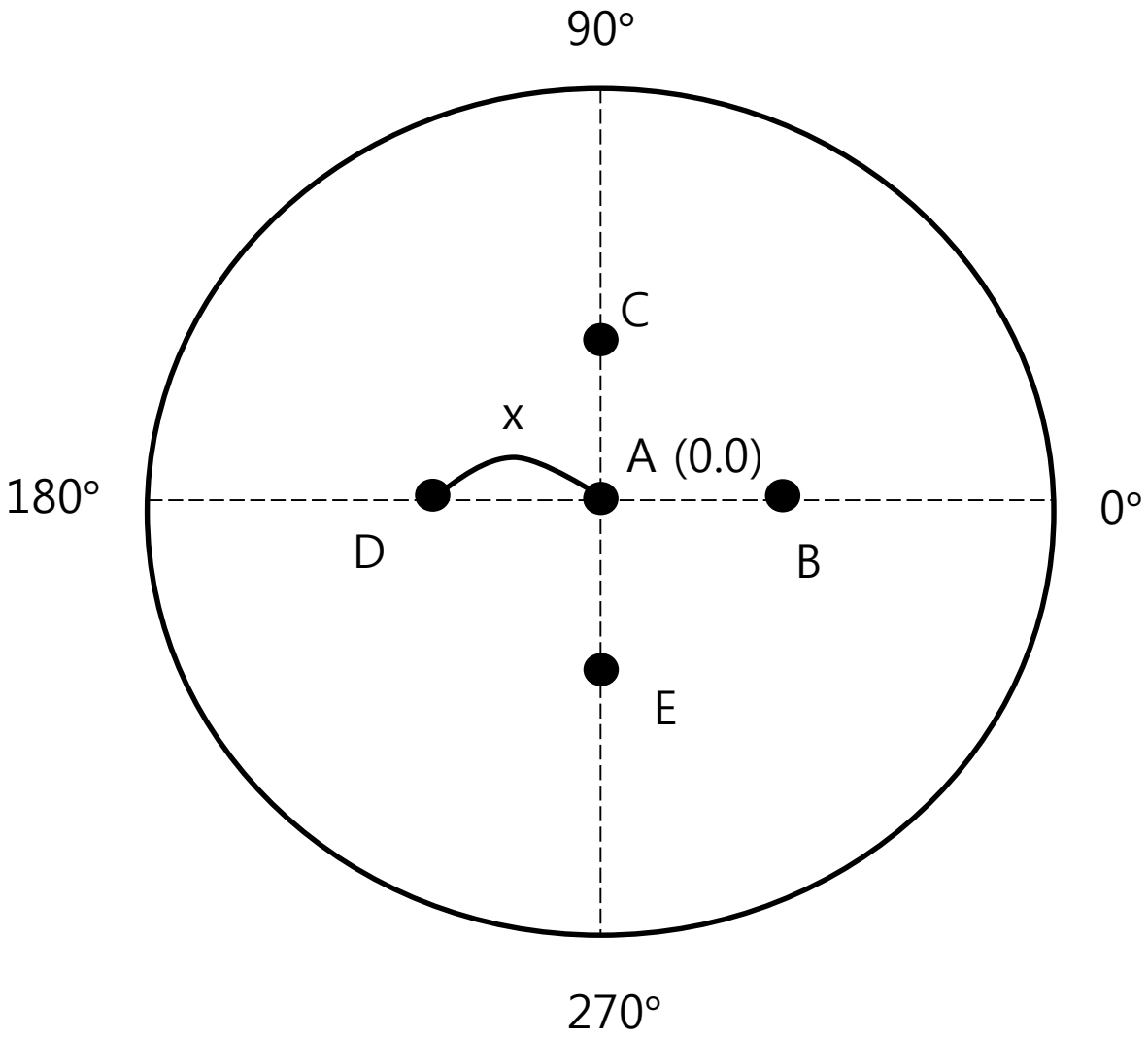
"Physics in Nuclear Medicine"

LOR : Line of Response



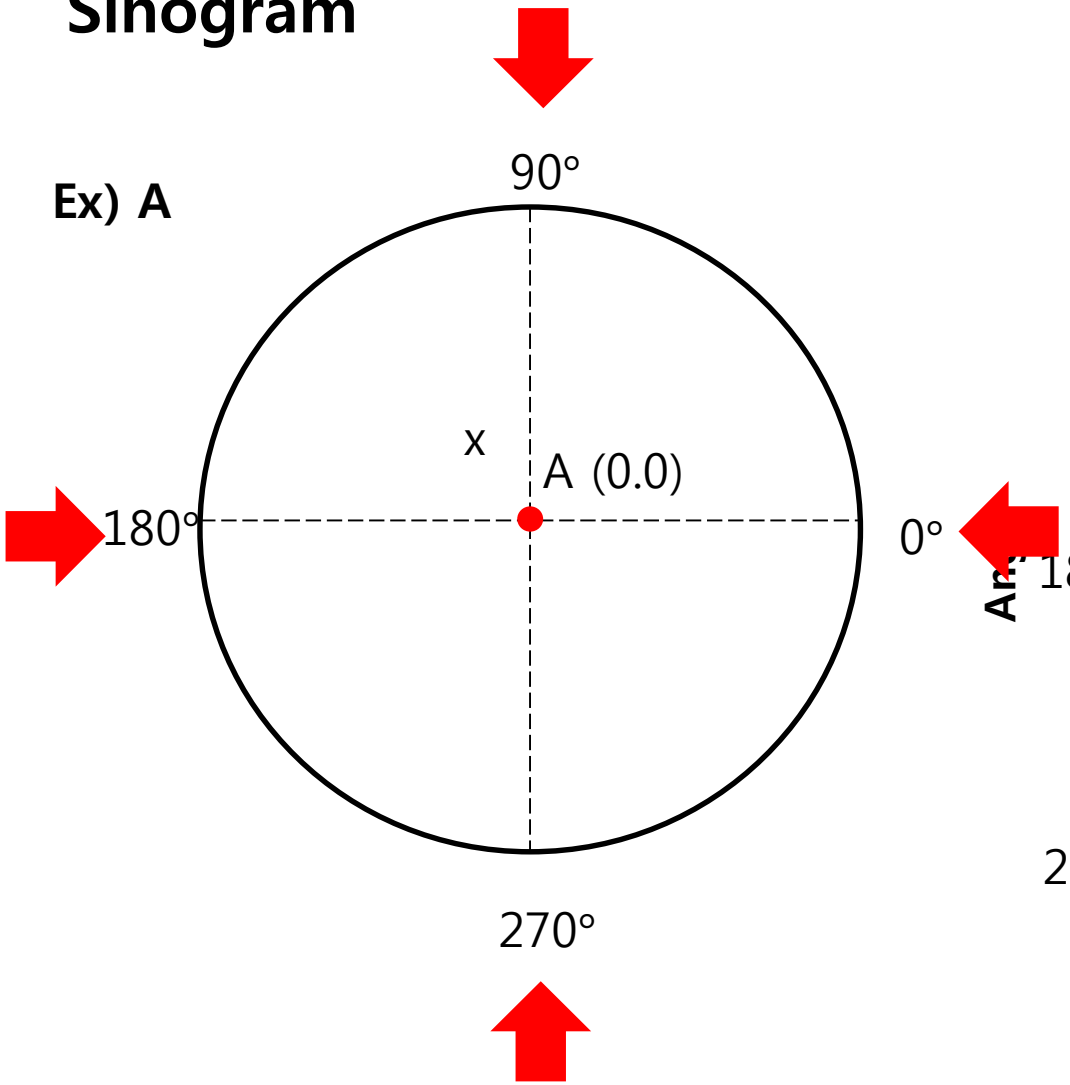


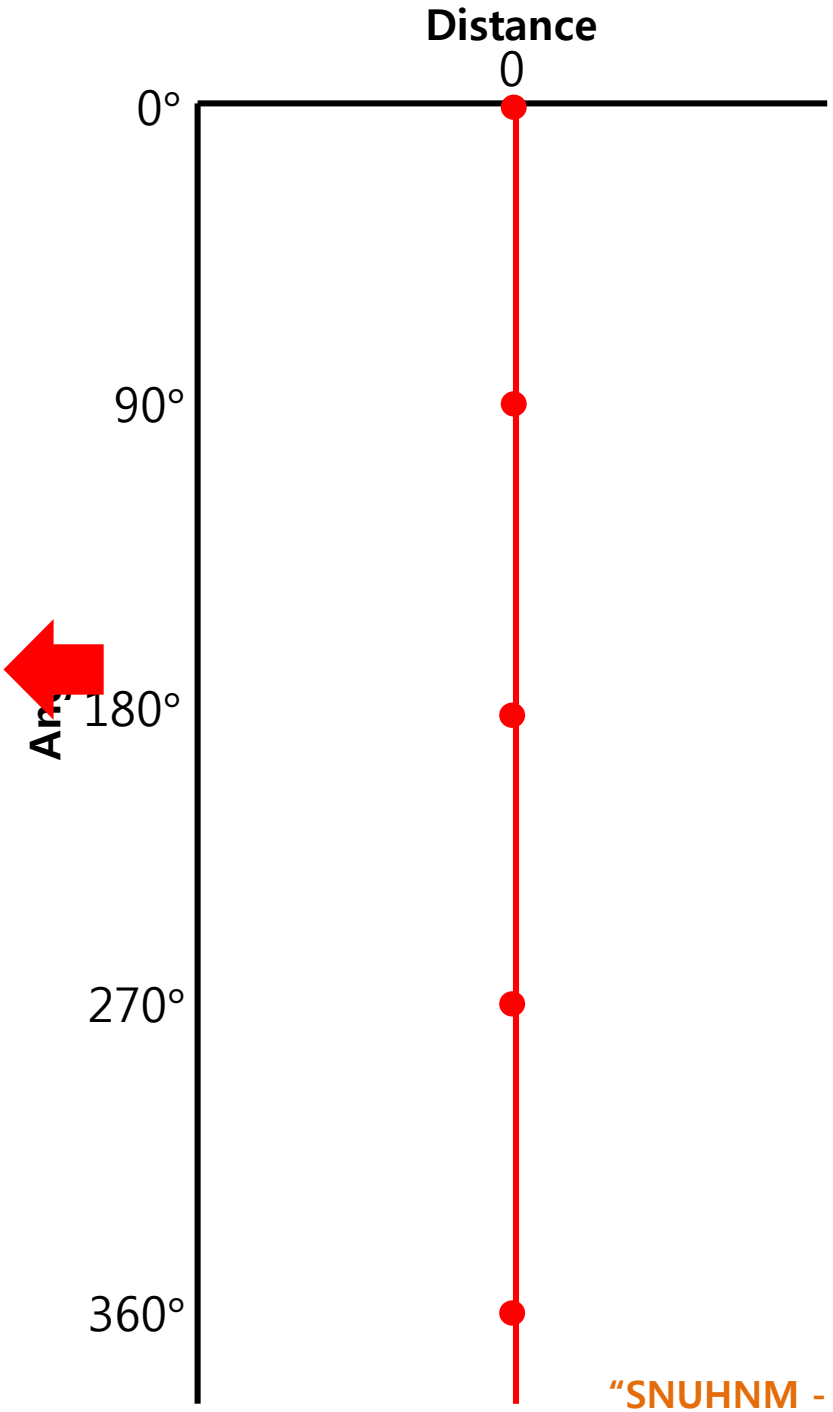
Sinogram



Sinogram

Ex) A

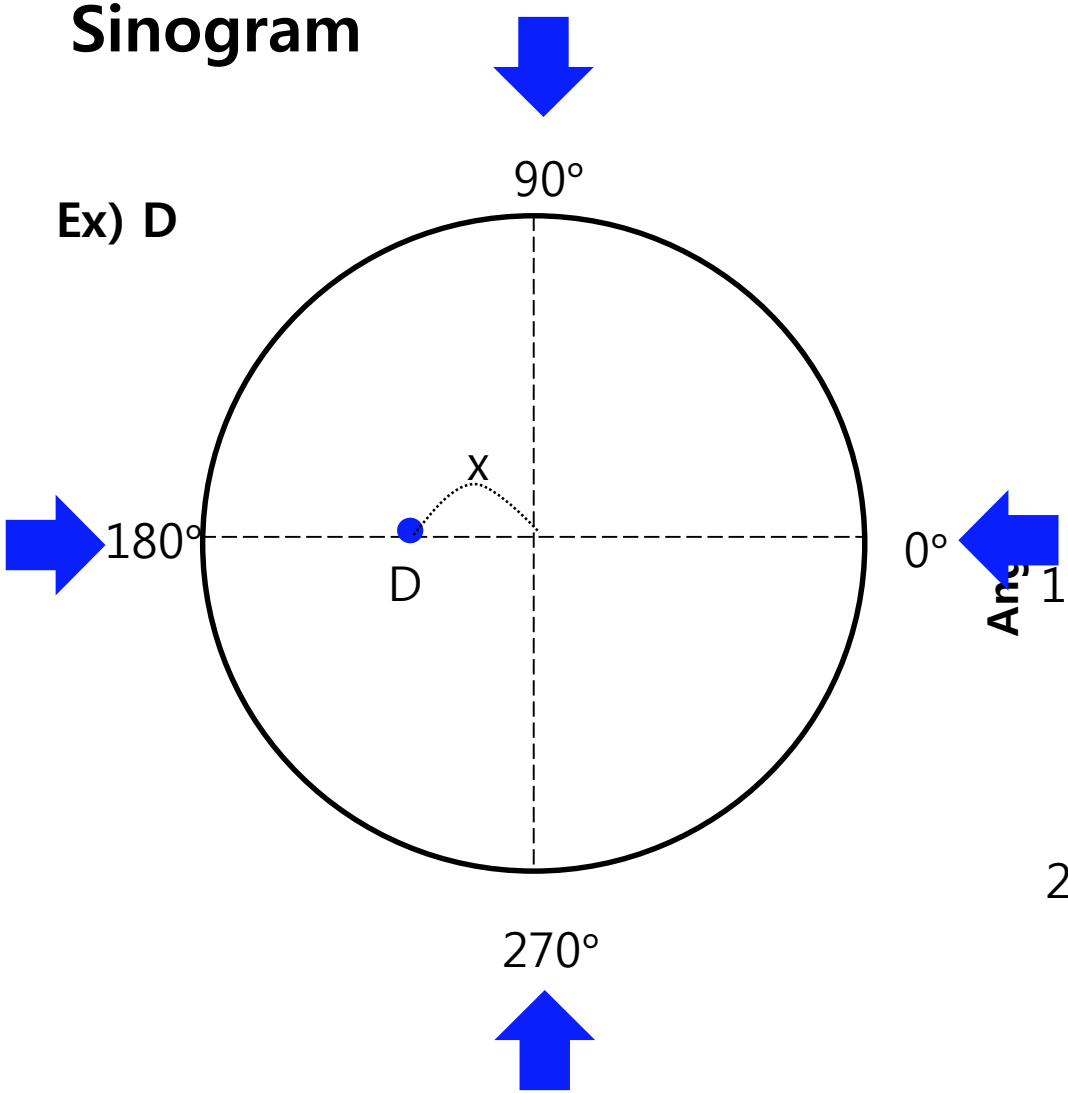


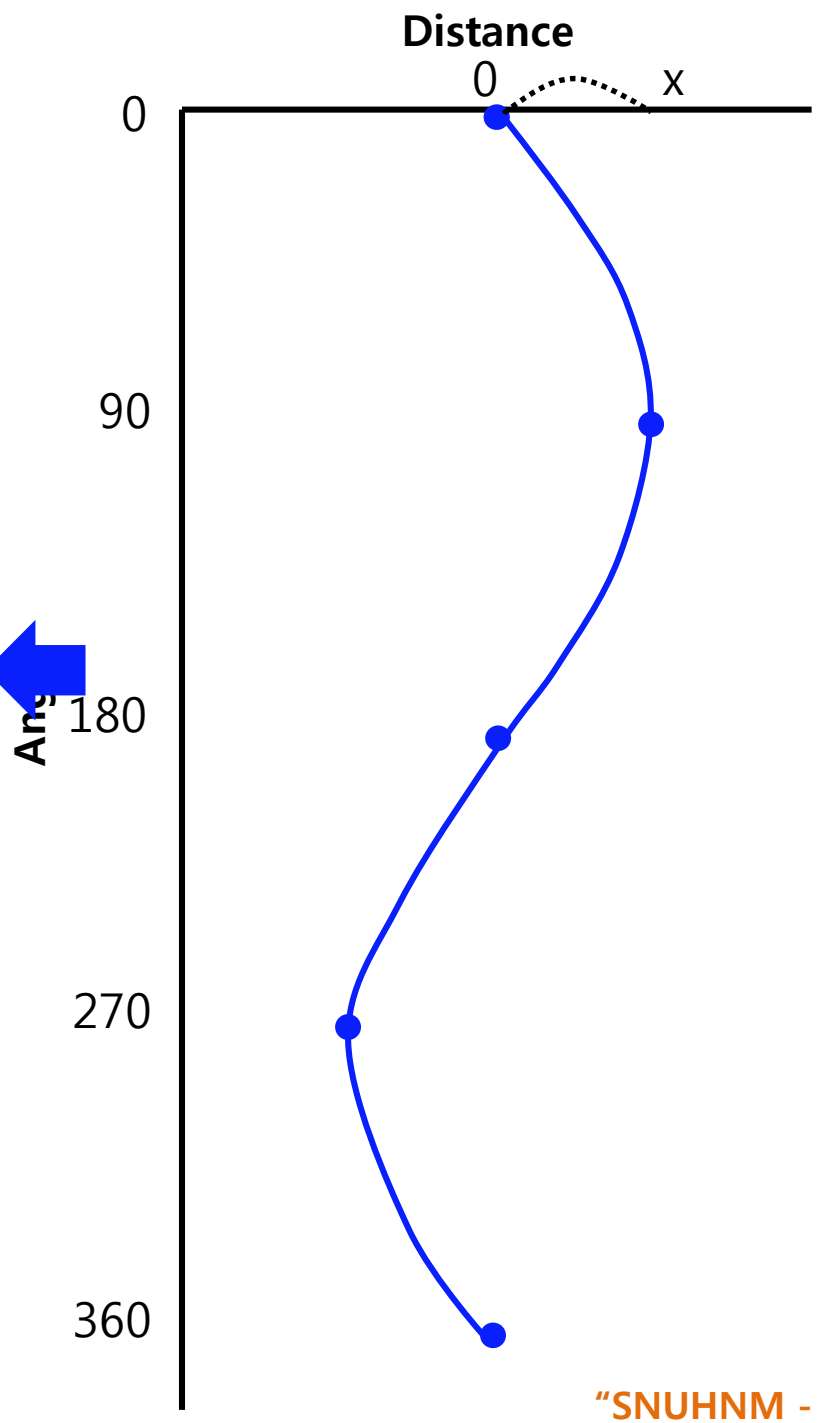


"SNUHNM - KMS"

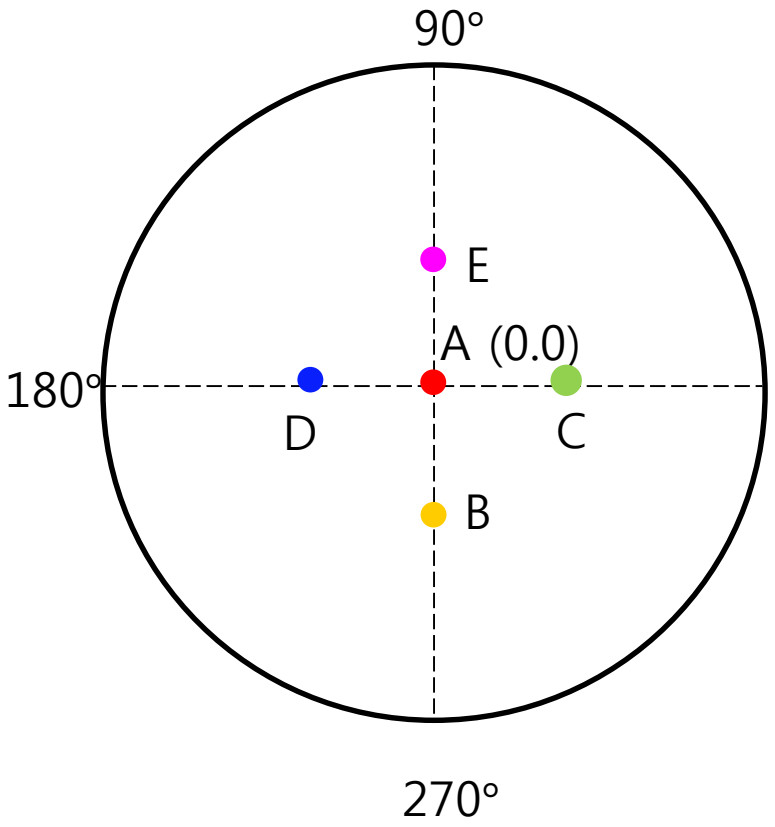
Sinogram

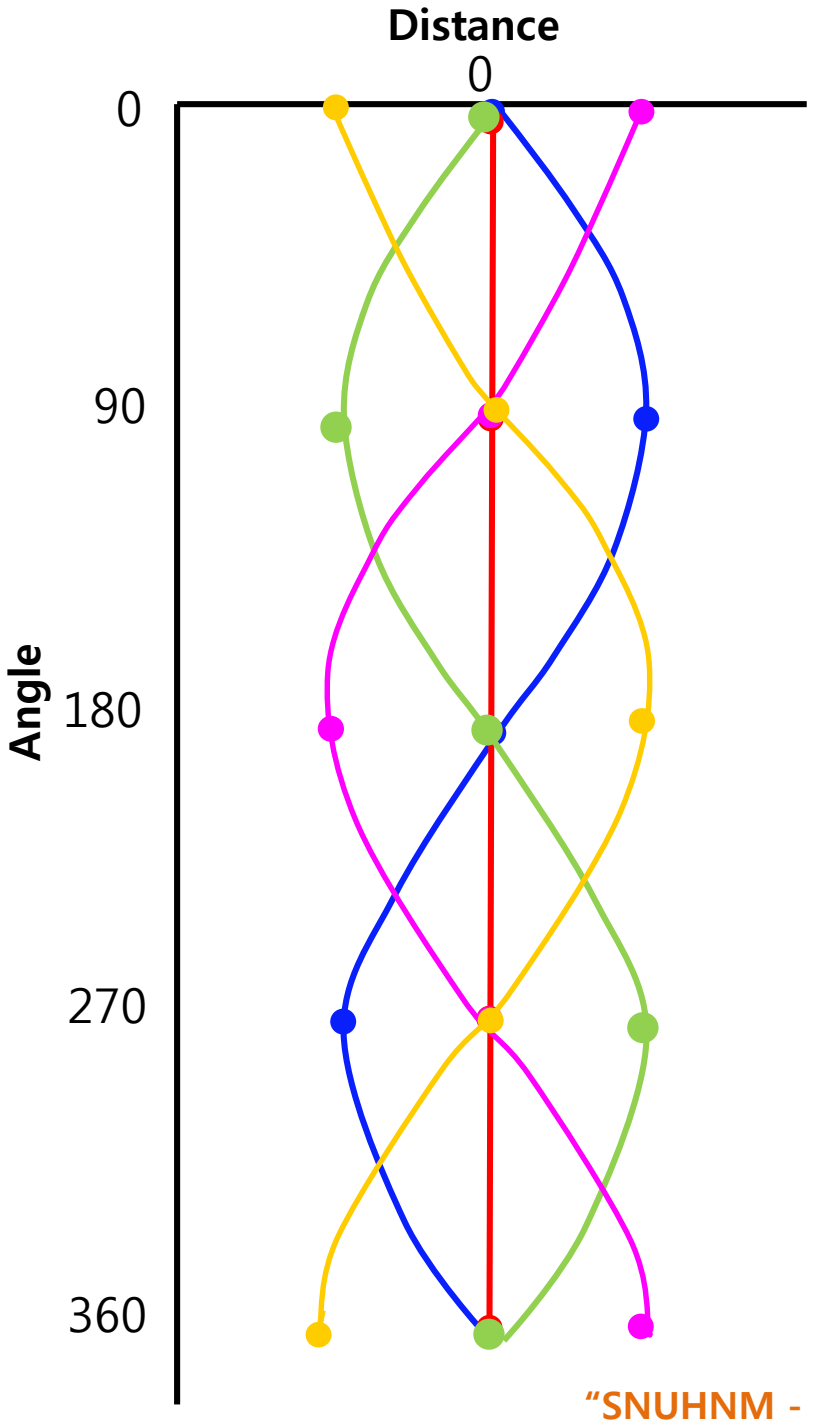
Ex) D



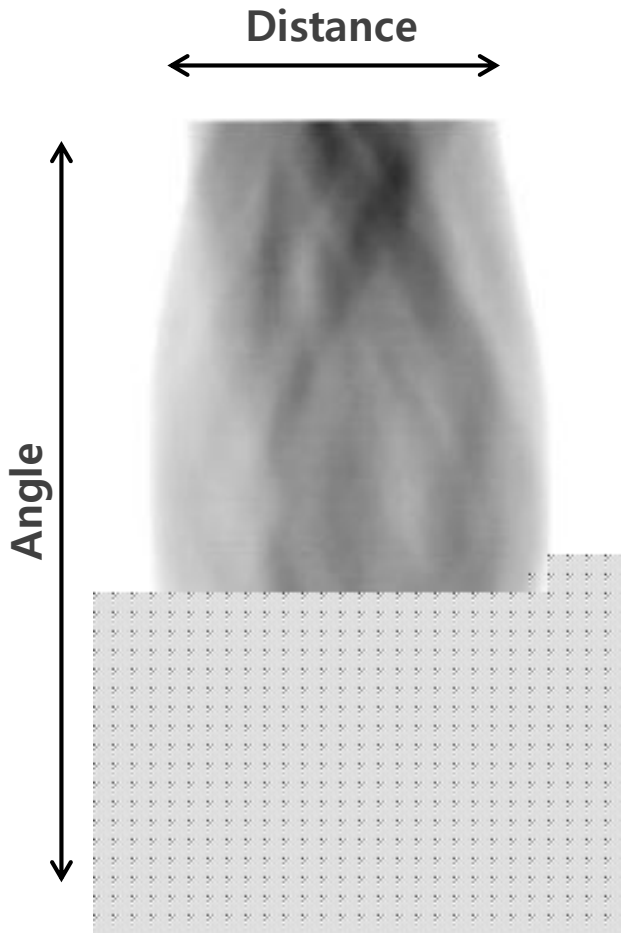


Sinogram





Sinogram



Sinogram

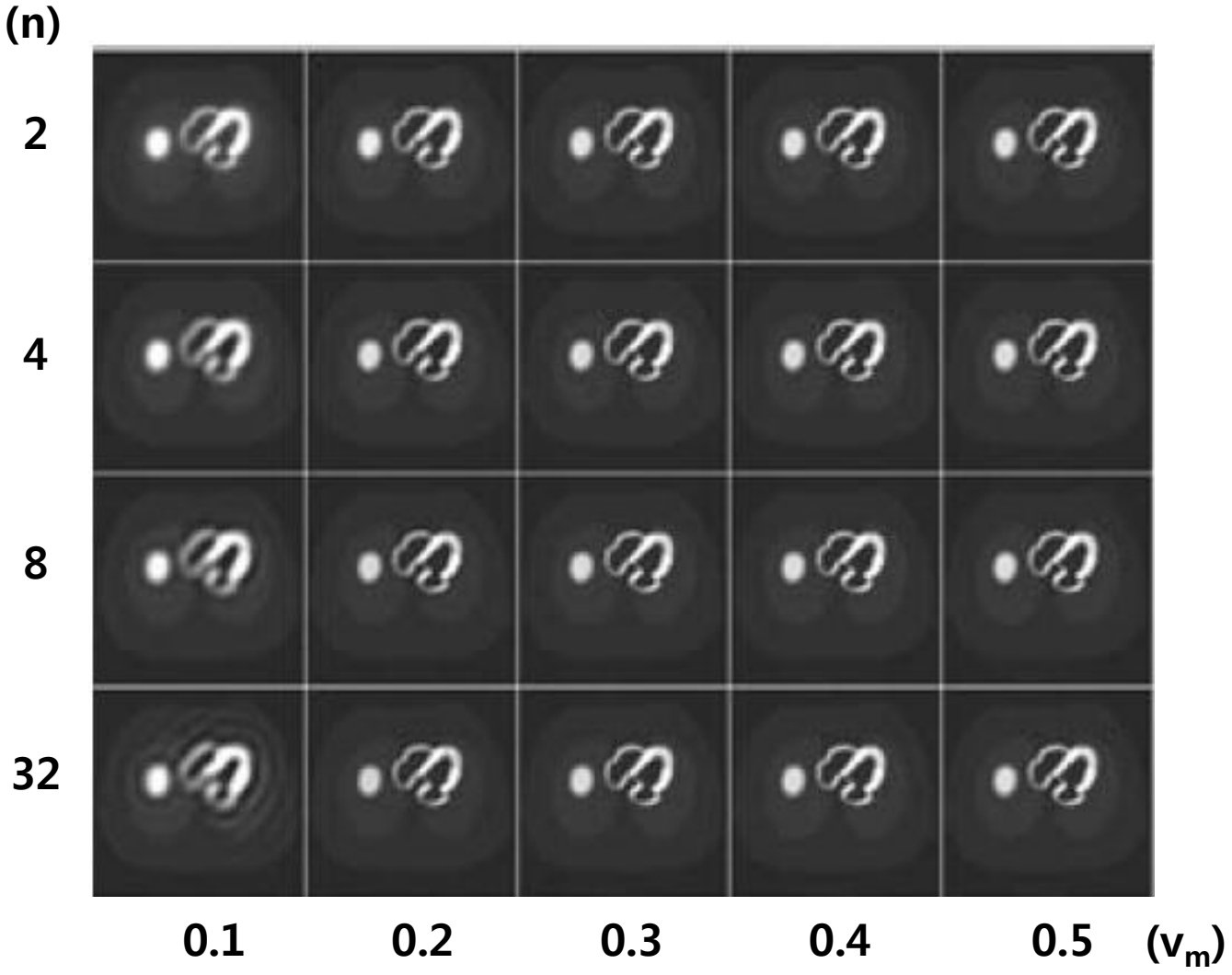
Reconstructed image

Hanning filter : Cut-off frequency(v_m)

0.1 0.2 0.3 0.4 0.5 (v_m)

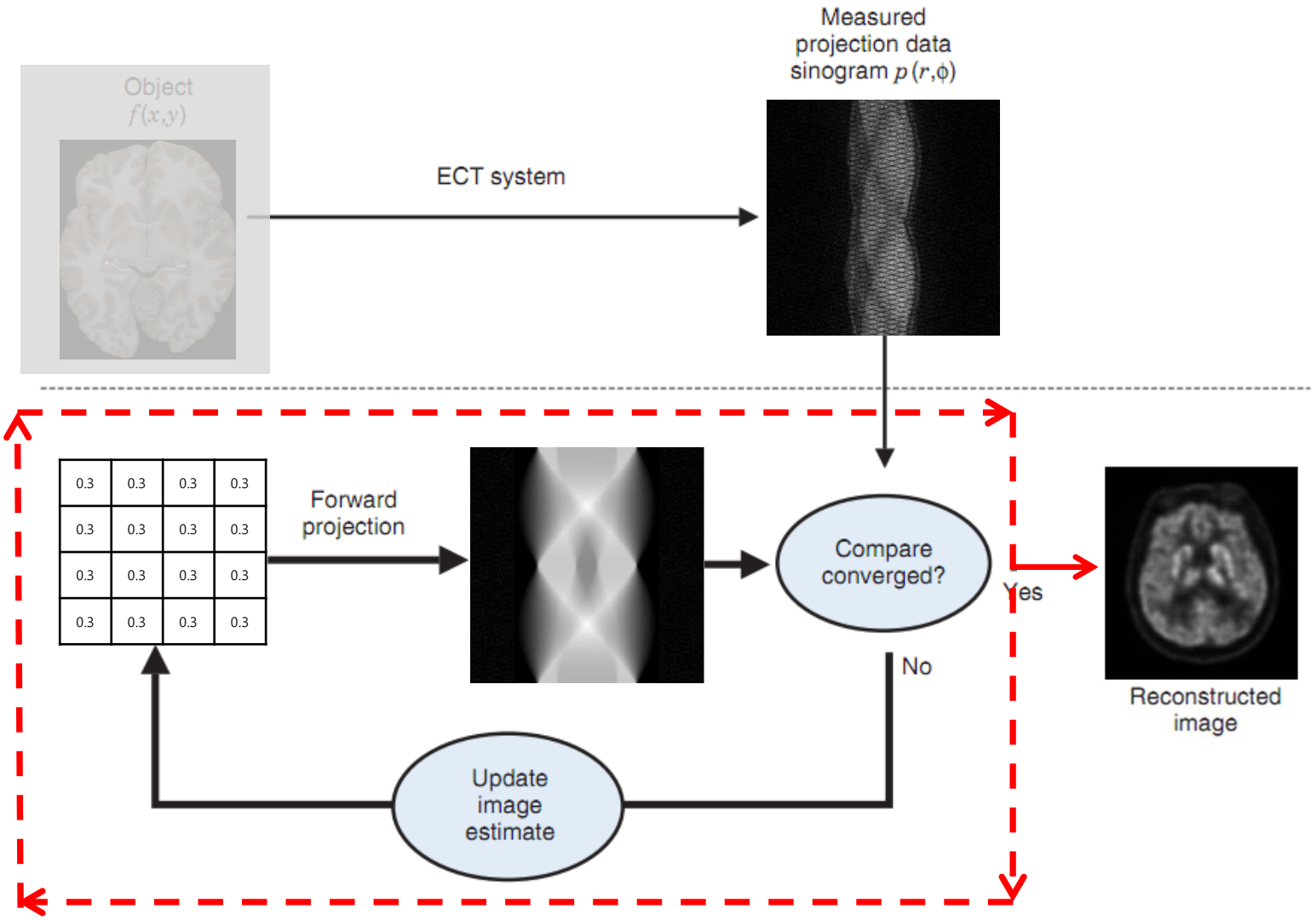
Cycle/pixel

Buttherworth filter : Order(n)

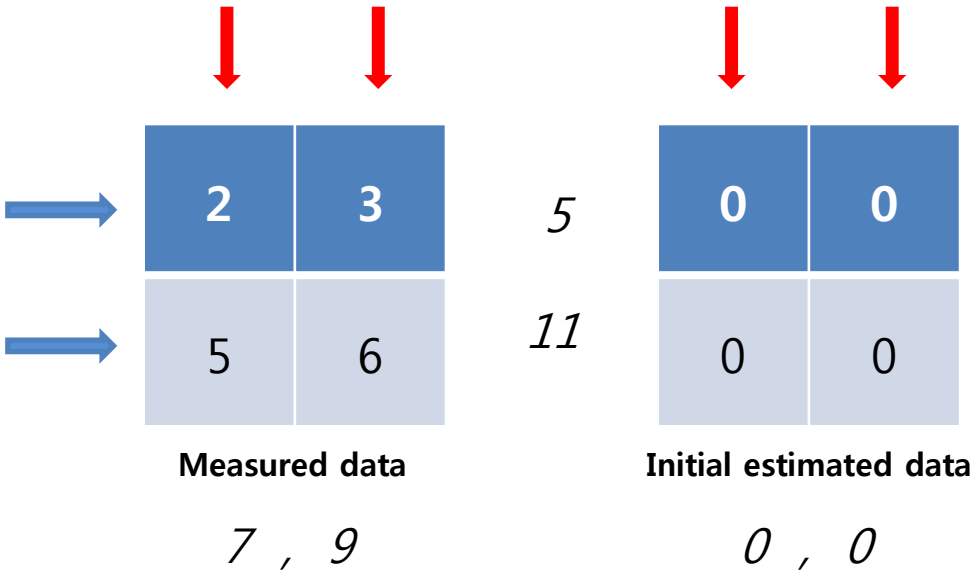


"Quantitative analysis in nuclear medicine"

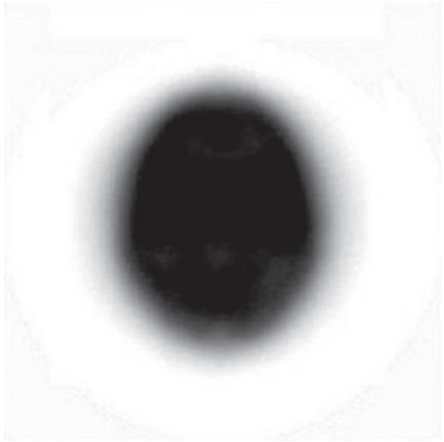
EM(Expectation Maximization)



EM(Expectation Maximization)



EM(Expectation Maximization)

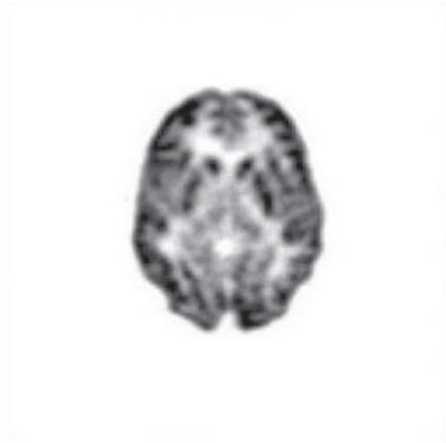


Iteration : 1

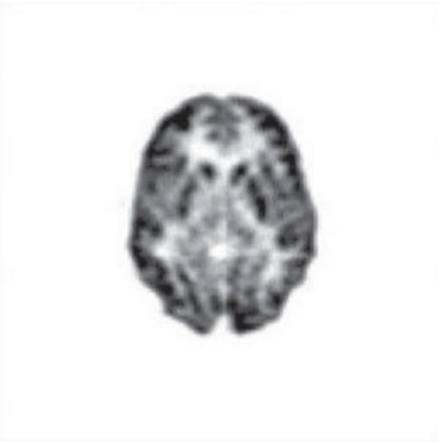
Iteration : 3

Iteration : 5

Iteration : 10



Iteration : 20



Iteration : 30

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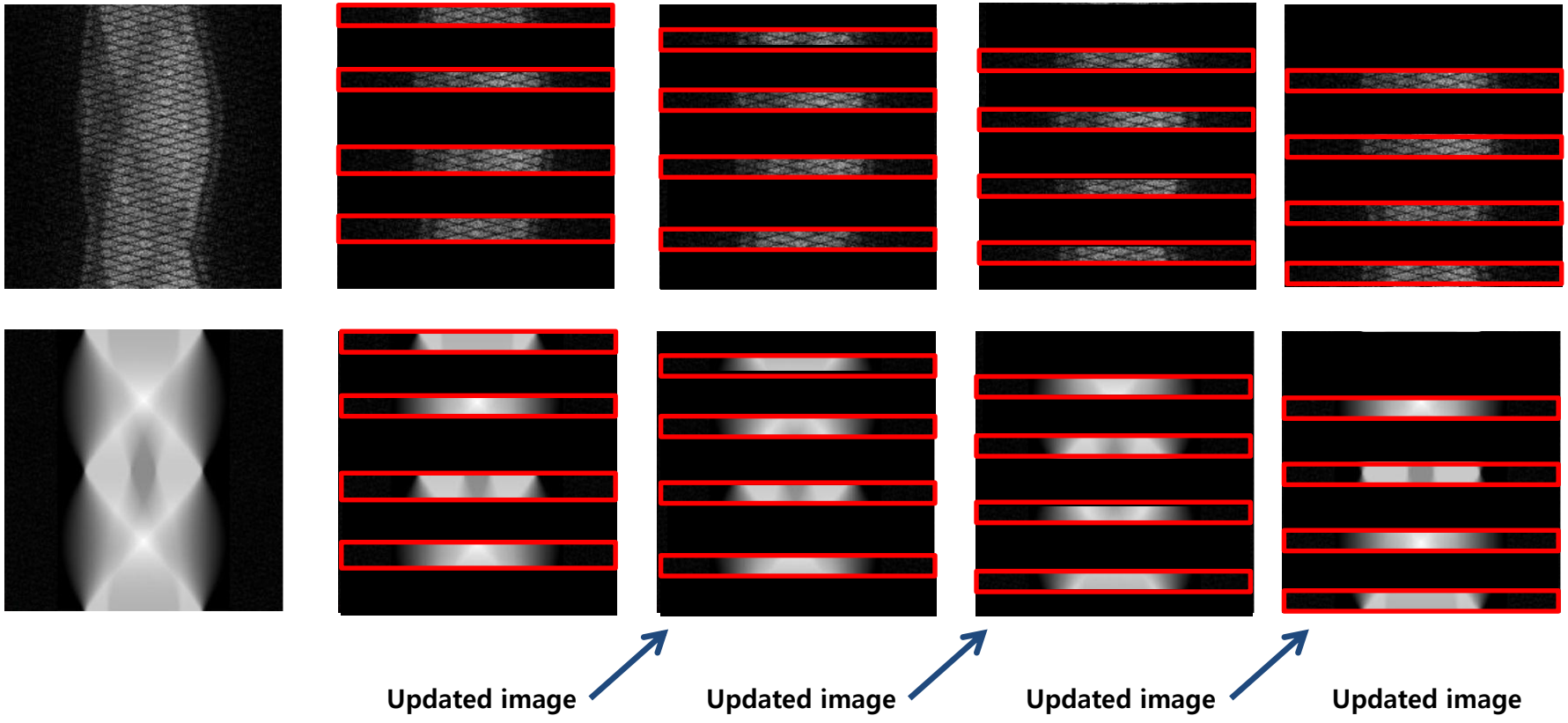
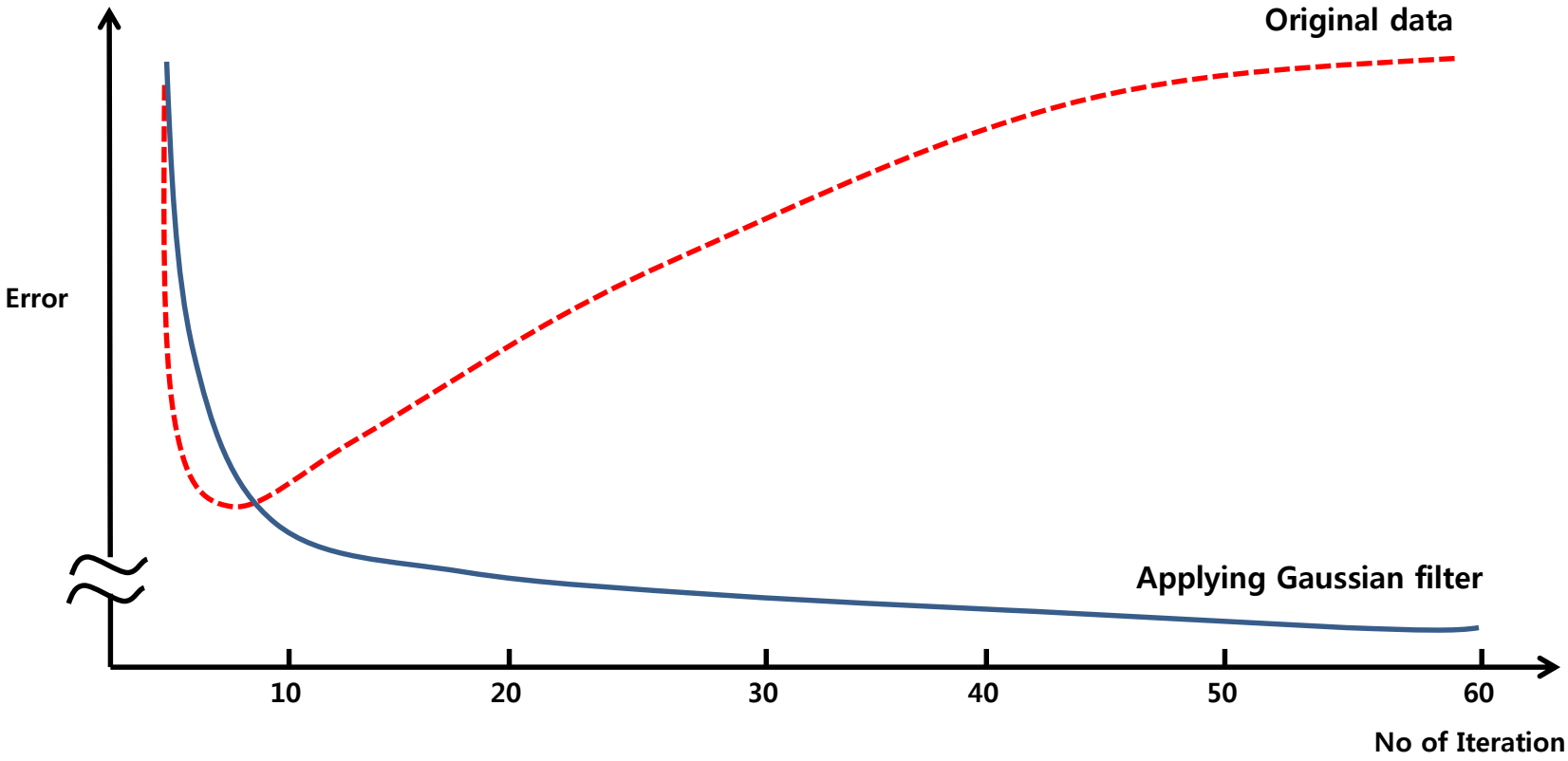
OSEM(Ordered Subset EM)

1. Subdivides projection data into several subsets, performs EM algorithm in each subset.
2. The OS-EM algorithm accelerates convergence by a factor proportional to the number of subsets.

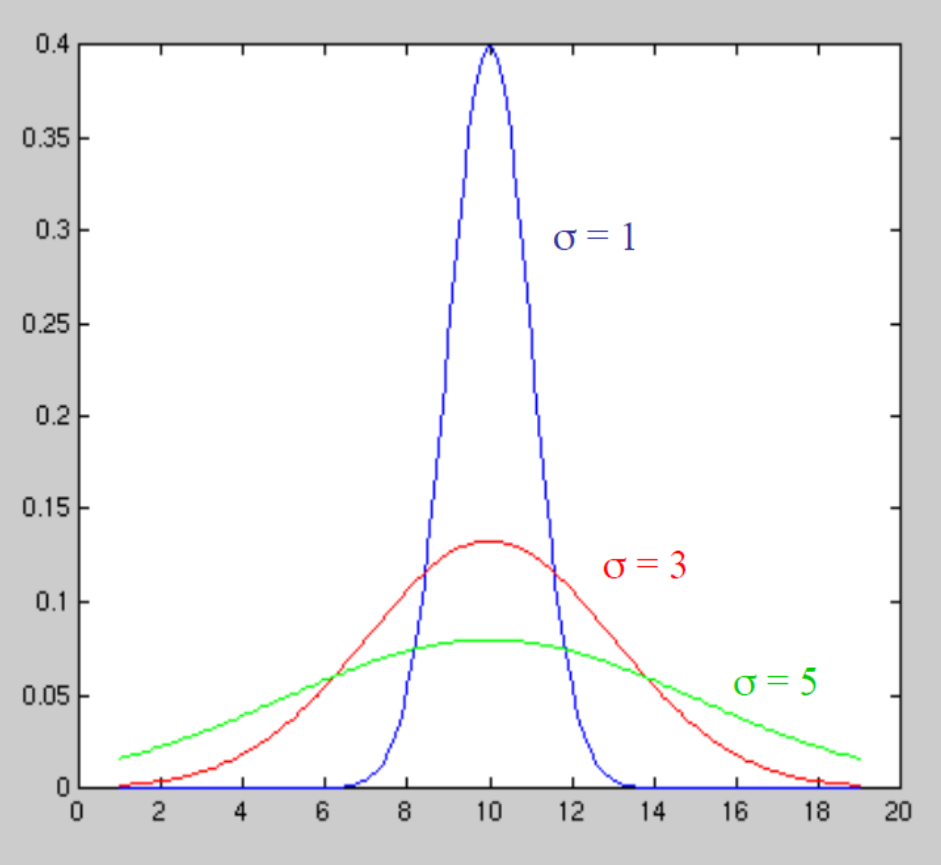


Gaussian Post Filter



Gaussian Post Filter

- Shape of Gaussian filter as function of σ -



$$\sigma = \frac{FWHM}{2\sqrt{2\ln 2}}$$

$$G(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{x^2}{2\sigma^2}}$$

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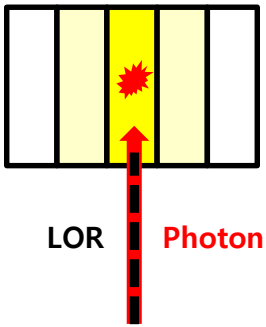
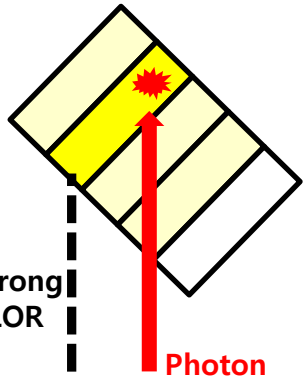
Point Spread Function

Point Spread Function

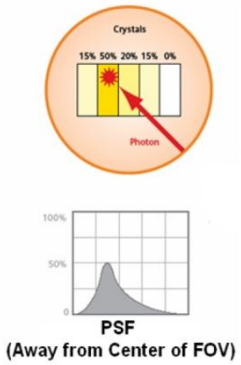
Before Correction

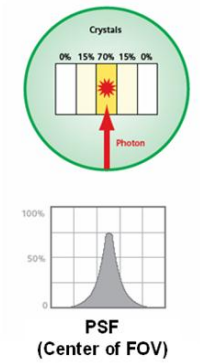


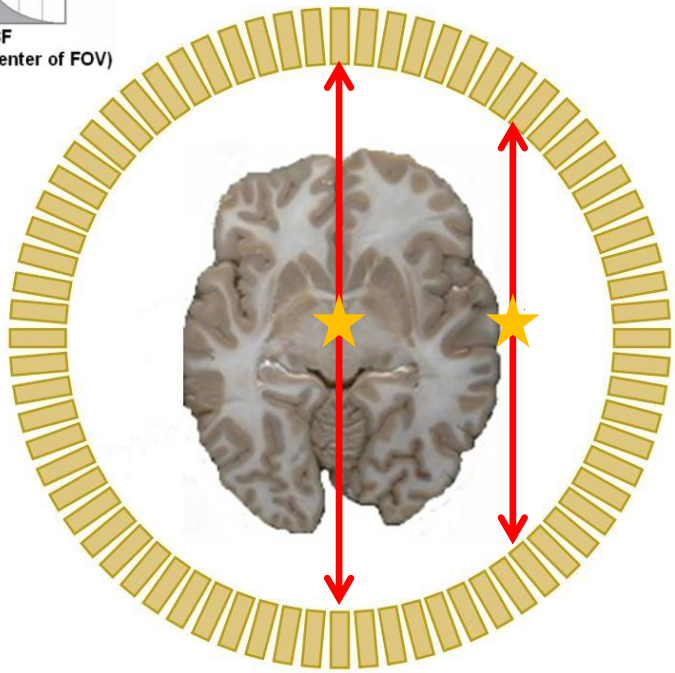
LOR Matched



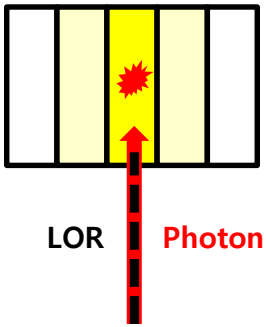
LOR *Mismatched*



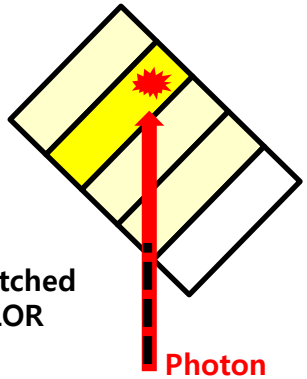




After Correction



LOR Matched



LOR Matched

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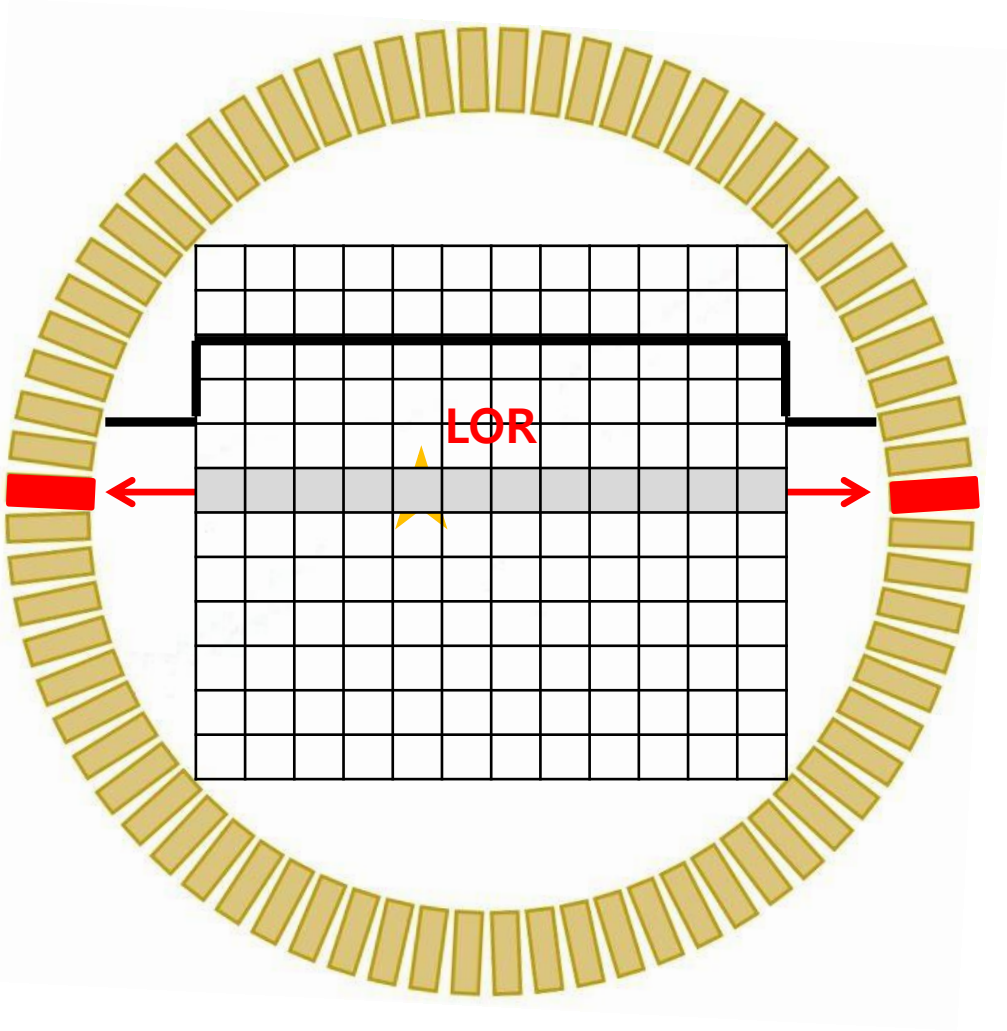
Time of Flight

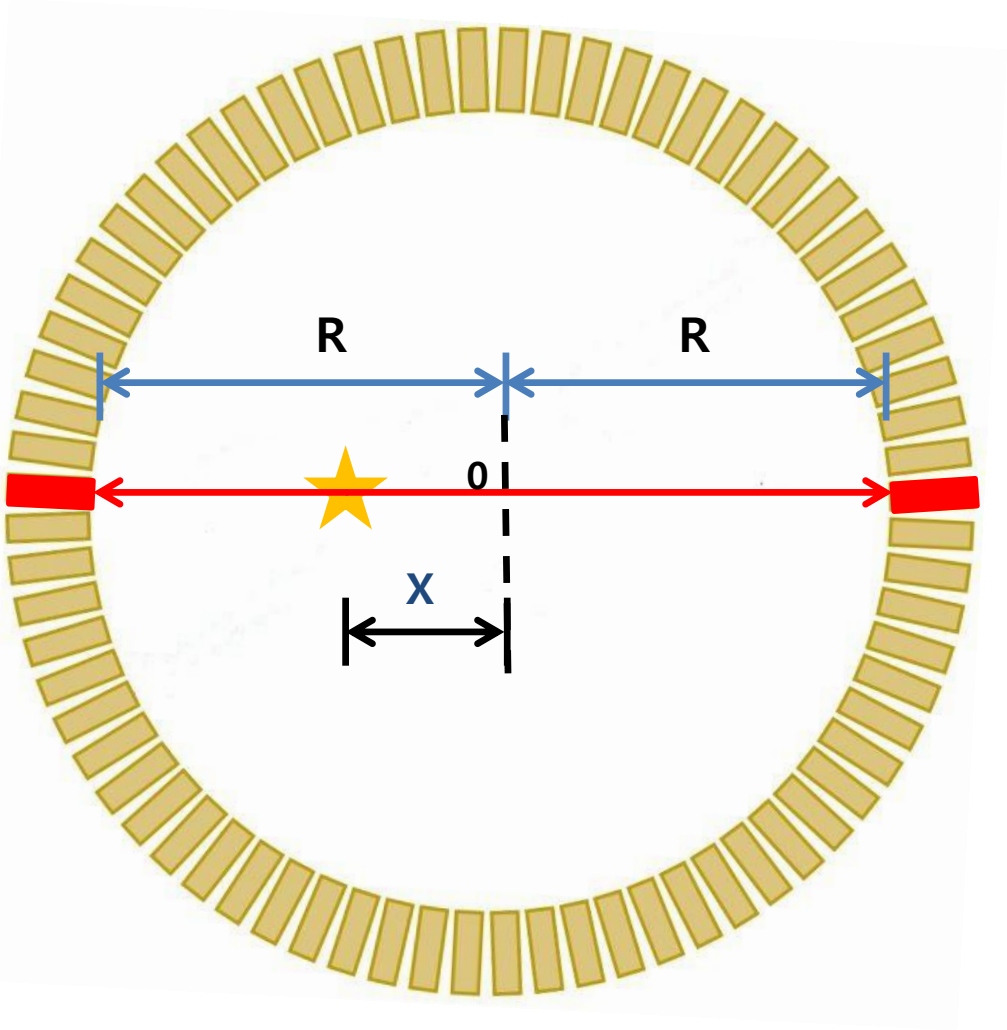
Time of Flight
- Conventional PET



Conventional back-projection

- **Uniform probability** along the LOR

Time of Flight
- Principle of TOF PET

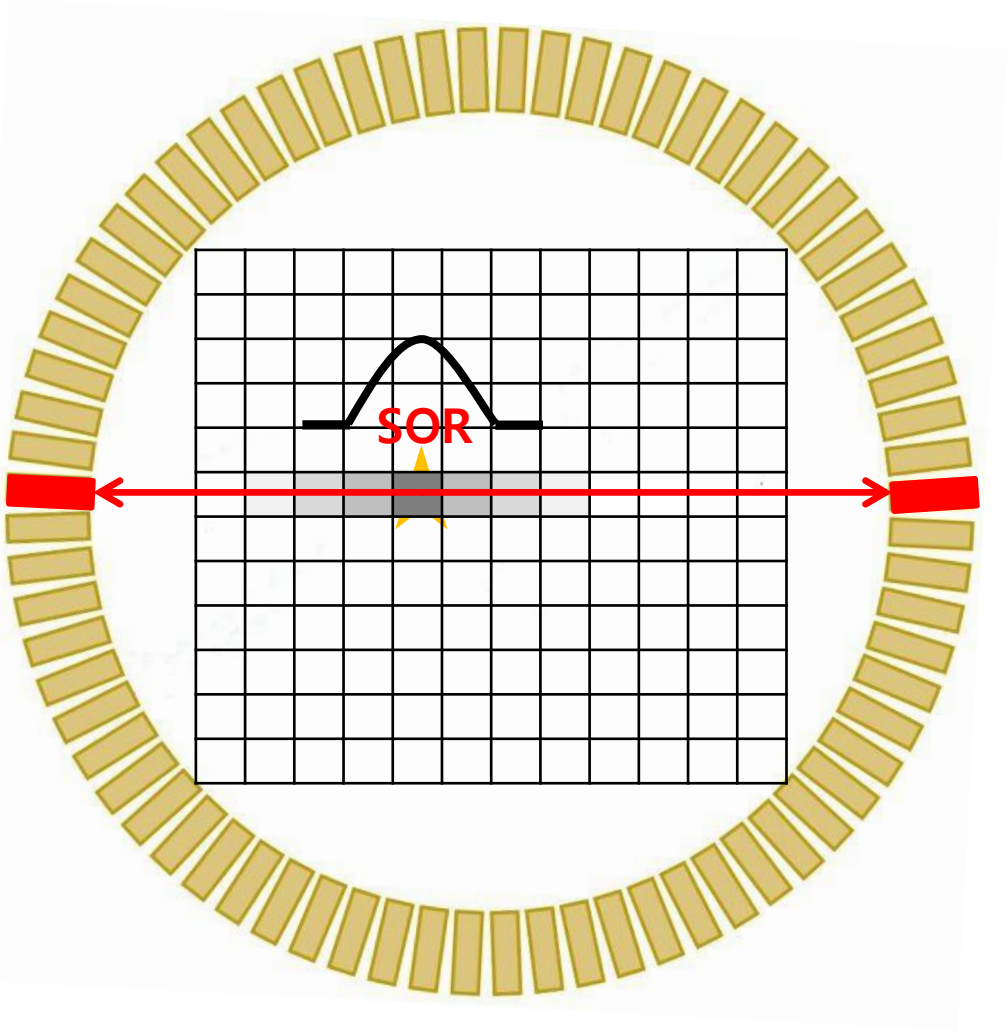


$$t_x = \frac{R+x}{c} - \frac{R-x}{c} = \frac{2x}{c}$$

$$x = \frac{c \times t_x}{2}$$

$$c = 2.997 \times 10^8 m/s$$

Time of Flight
- TOF PET

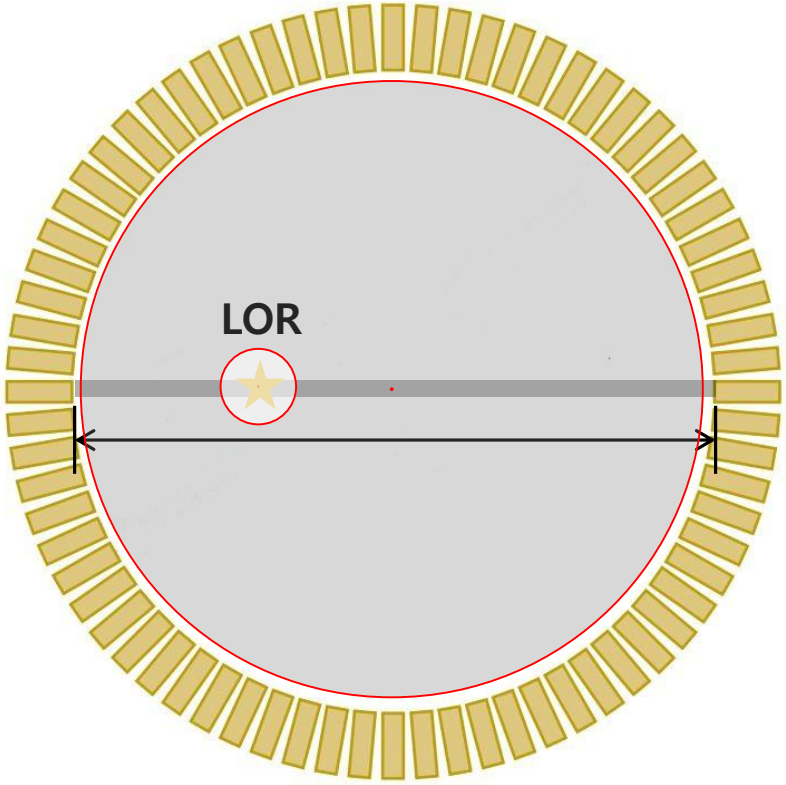


Using Time of Flight information

- **Limited probability** along the SOR
- SOR is proportional to time resolution of system

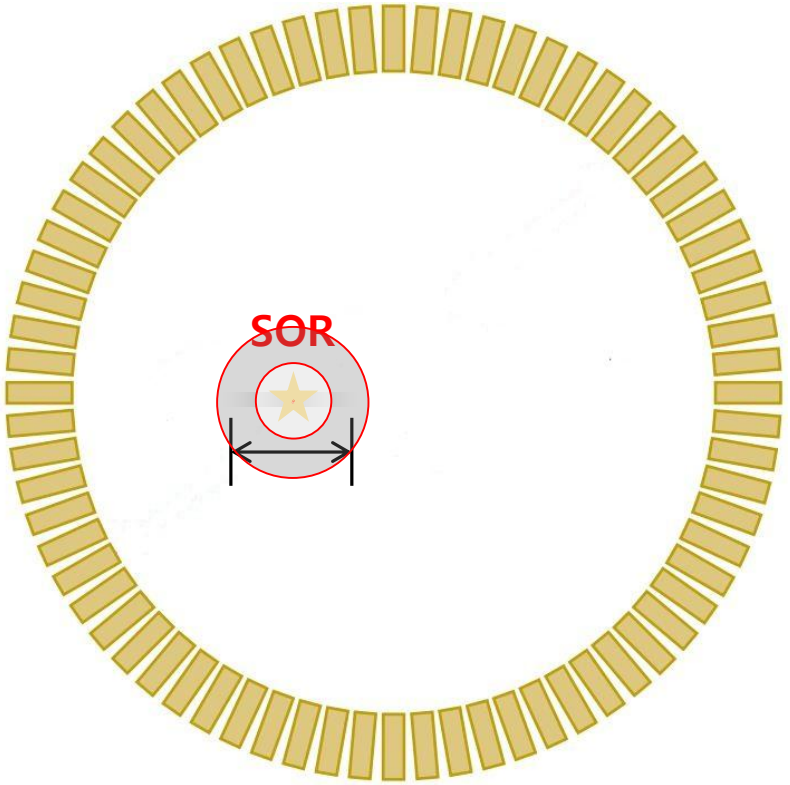
LOR vs SOR - Noise

Conventional PET



LOR : Line of Response
- Uniform probability along the LOR
- Higher noise

TOF PET



SOR : Segment of Response
- Limited probability along the SOR
- Lower noise

"2013 영상발전 심포지움"

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CT Dose Reduction Methods

CT Parameters for ^{18}F-FDG Torso

Exposure Condition	120kV, 35mAs with **CAREdose4D, CAREkV, SAFIRE**		
Pitch	1.2		
Matrix Size	512*512		
Reconstruction Parameters	**AC-CT**	FOV	780 mm
		Kernel	B26f medium smooth ASA
		Slice Thickness	5.0 mm
		Increment	3.0 mm
	Diagnostic-CT	FOV	500 mm
		Kernel	I30f medium smooth
		Slice Thickness	3.0 mm
		Increment	2.0 mm

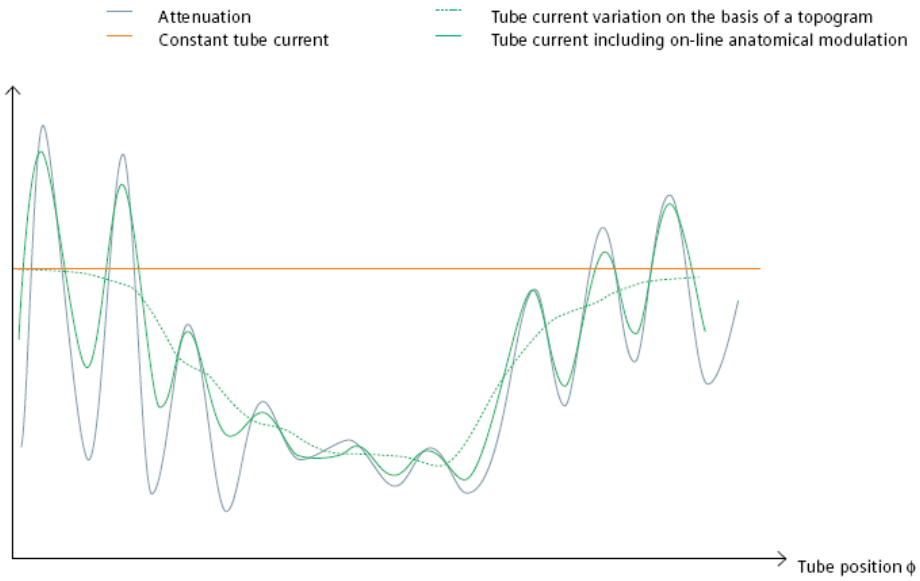
Real-time Automatic Exposure Control

1) Purpose

- Minimize radiation exposure
- Optimal image quality in every slice

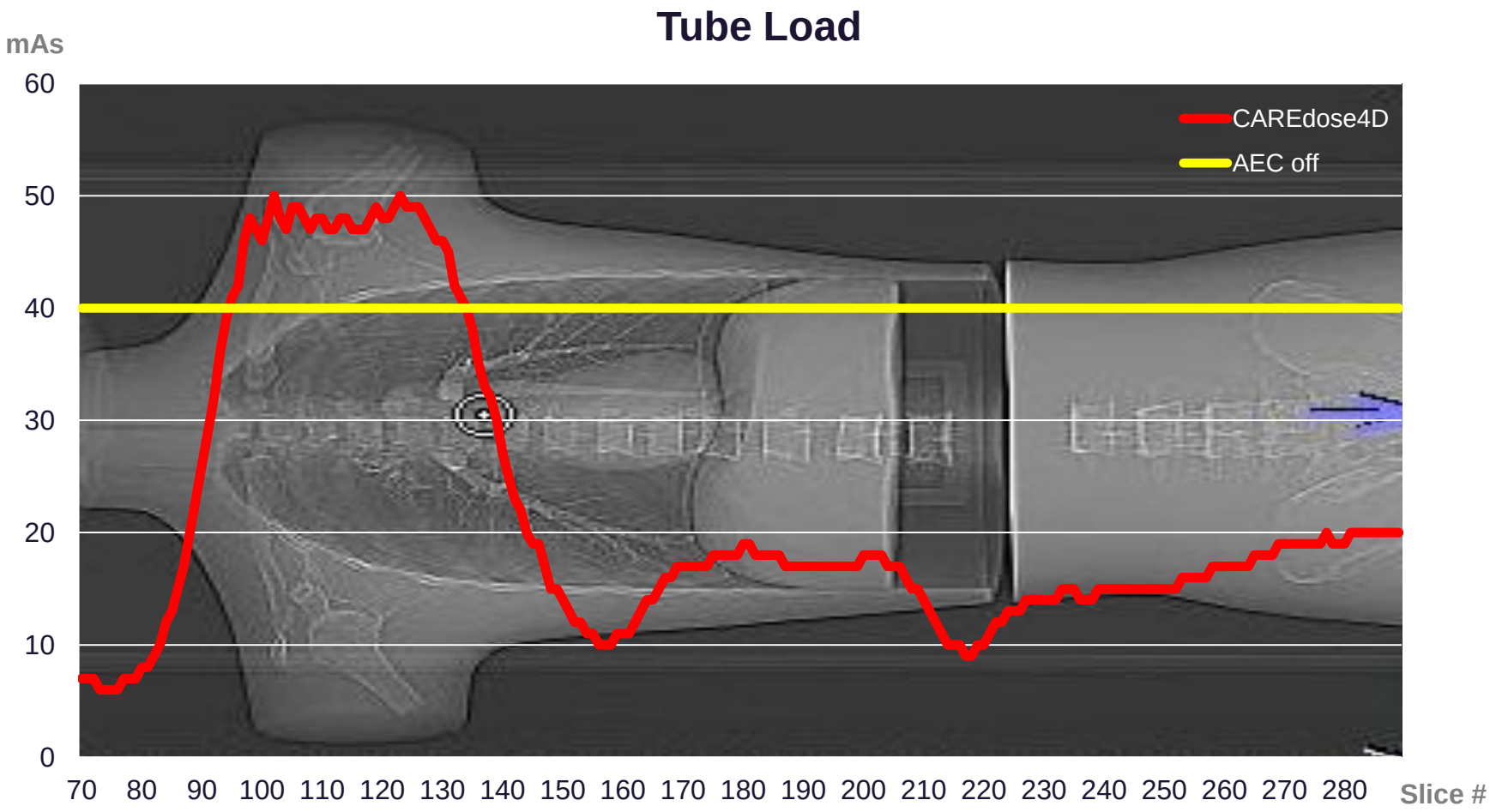
2) Principles

- Patient size and shape
- Z-axis(patient's long axis)
- Angular modulation



"CT Essentials : SIEMENS"

Real-time Automatic Exposure Control



"CT Essentials : SIEMENS"

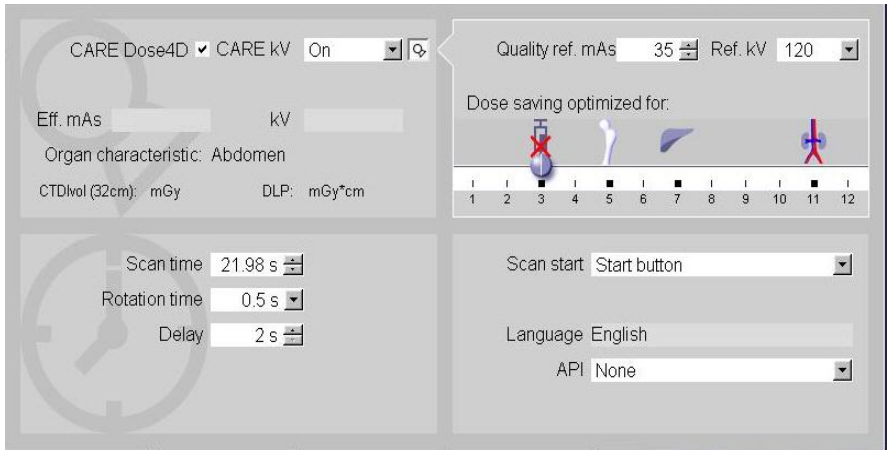
Automated Dose-optimized Selection of Tube Voltage

1) Purpose

- Optimized tube potential(kV)
- Minimize radiation exposure
- Optimizing CNR

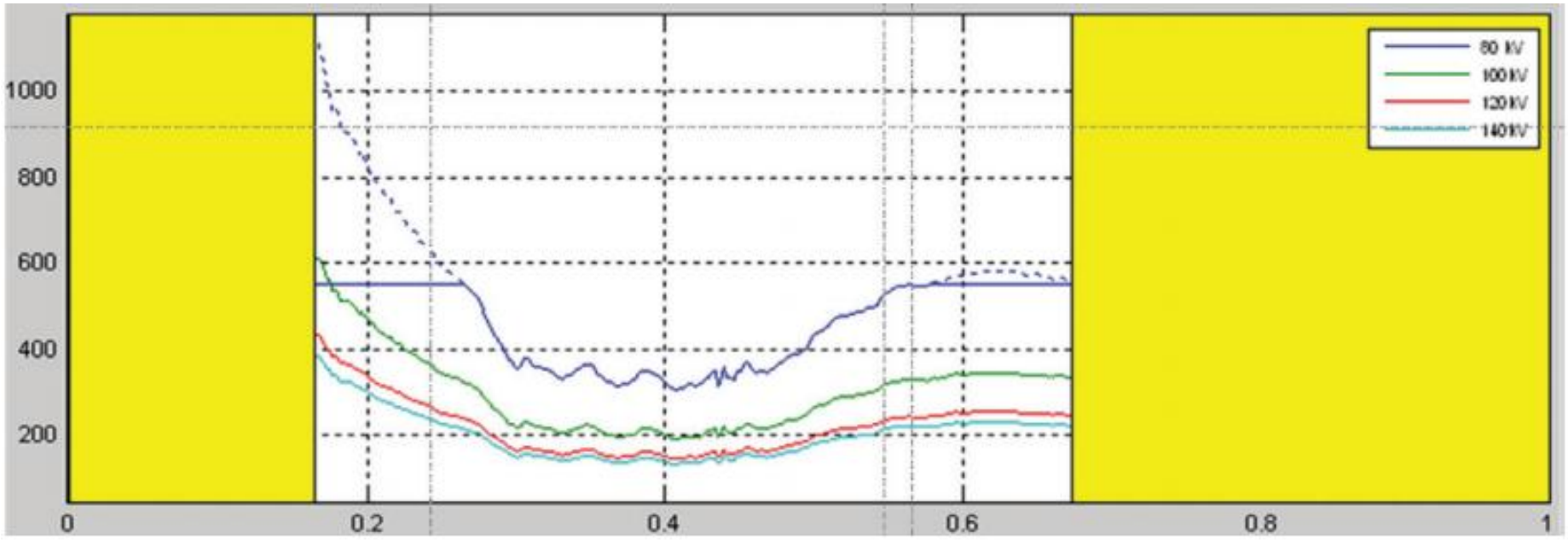
2) Principles

- Working with AEC
- Automatically suggest kV & eff. mAs



"CAREkV WP : SIEMENS"

Automated Dose-optimized Selection of Tube Voltage



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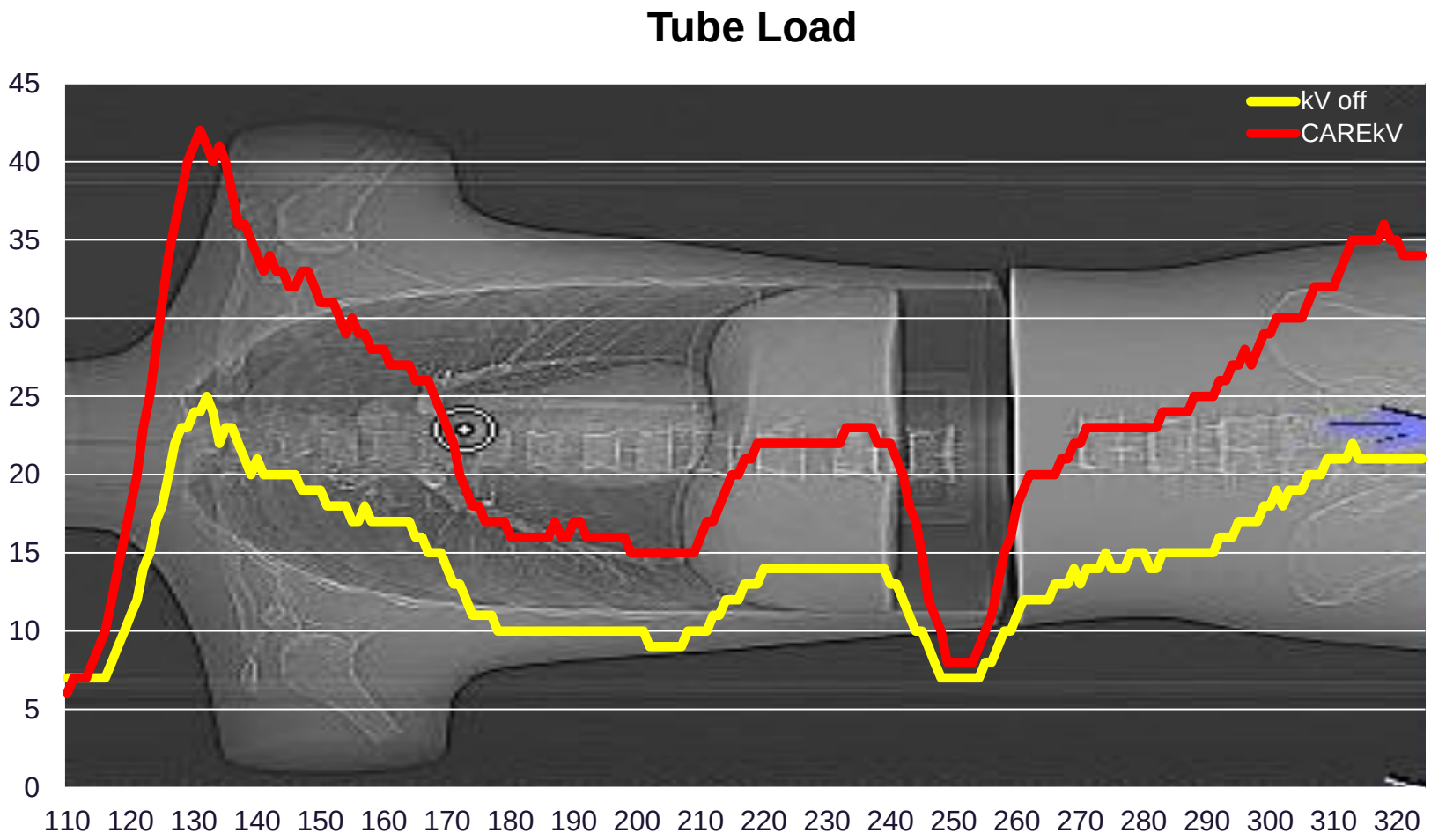
Automated Dose-optimized Selection of Tube Voltage



"CAREkV WP : SIEMENS"

Iterative Statistical CT Reconstruction

1) Purpose
- Image quality improvement
- Dose reduction

2) Principles
- Iterative reconstruction method
- Raw data space : Artifact remover
- Image space : Noise reduction

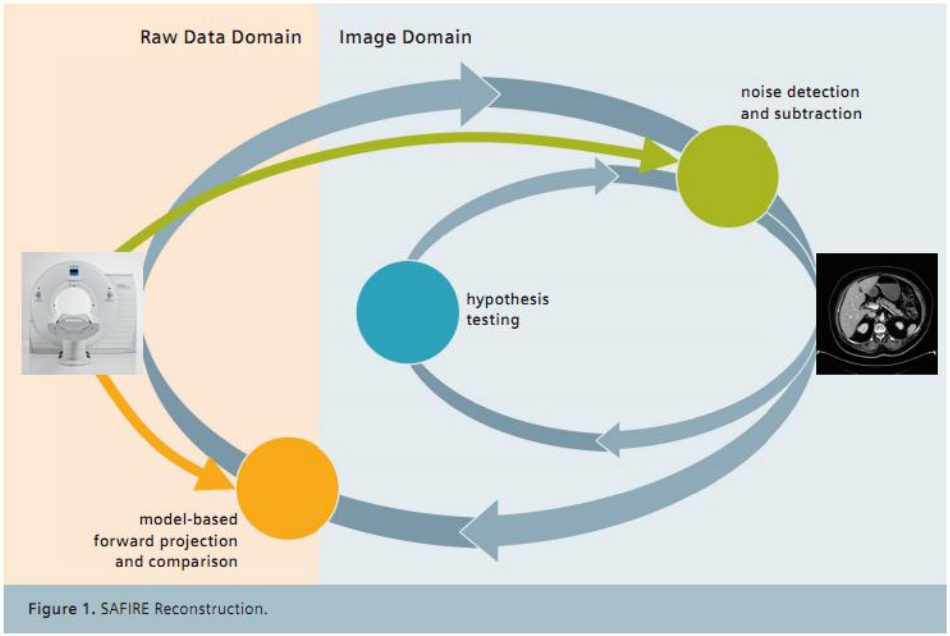
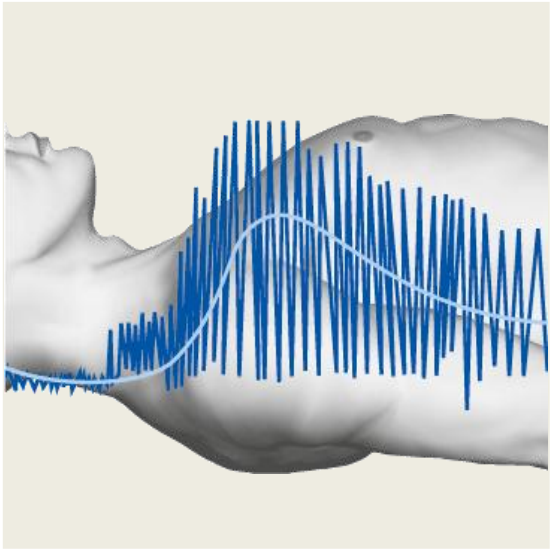


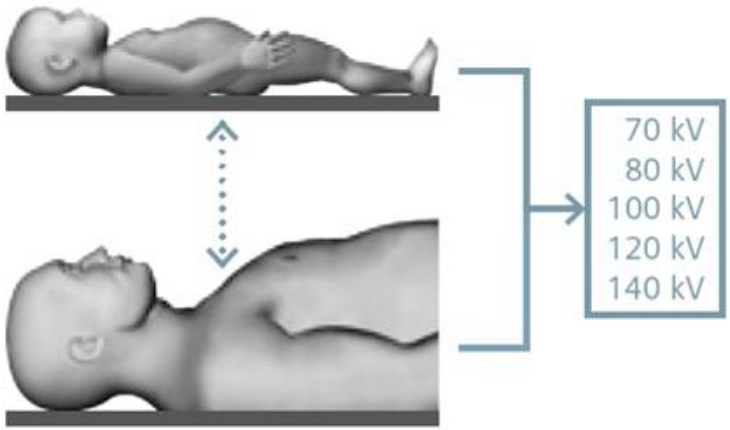
Figure 1. SAFIRE Reconstruction.

"SAFIRE WP : SIEMENS"

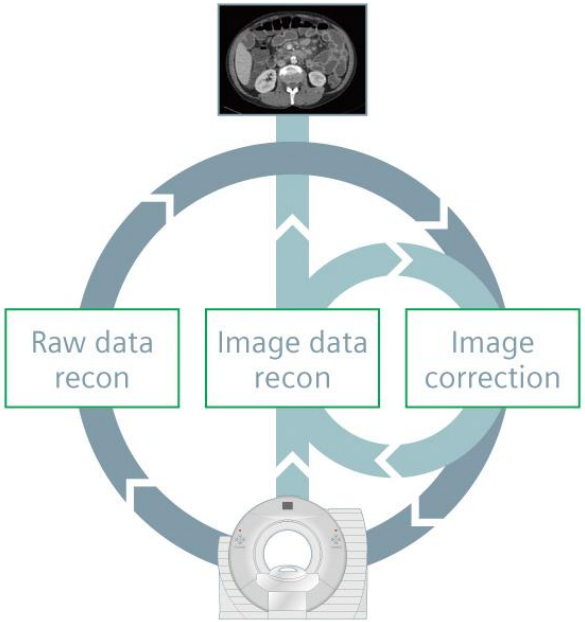
Combination of 3 Methods for CT Dose Reduction



Automatic Exposure Control

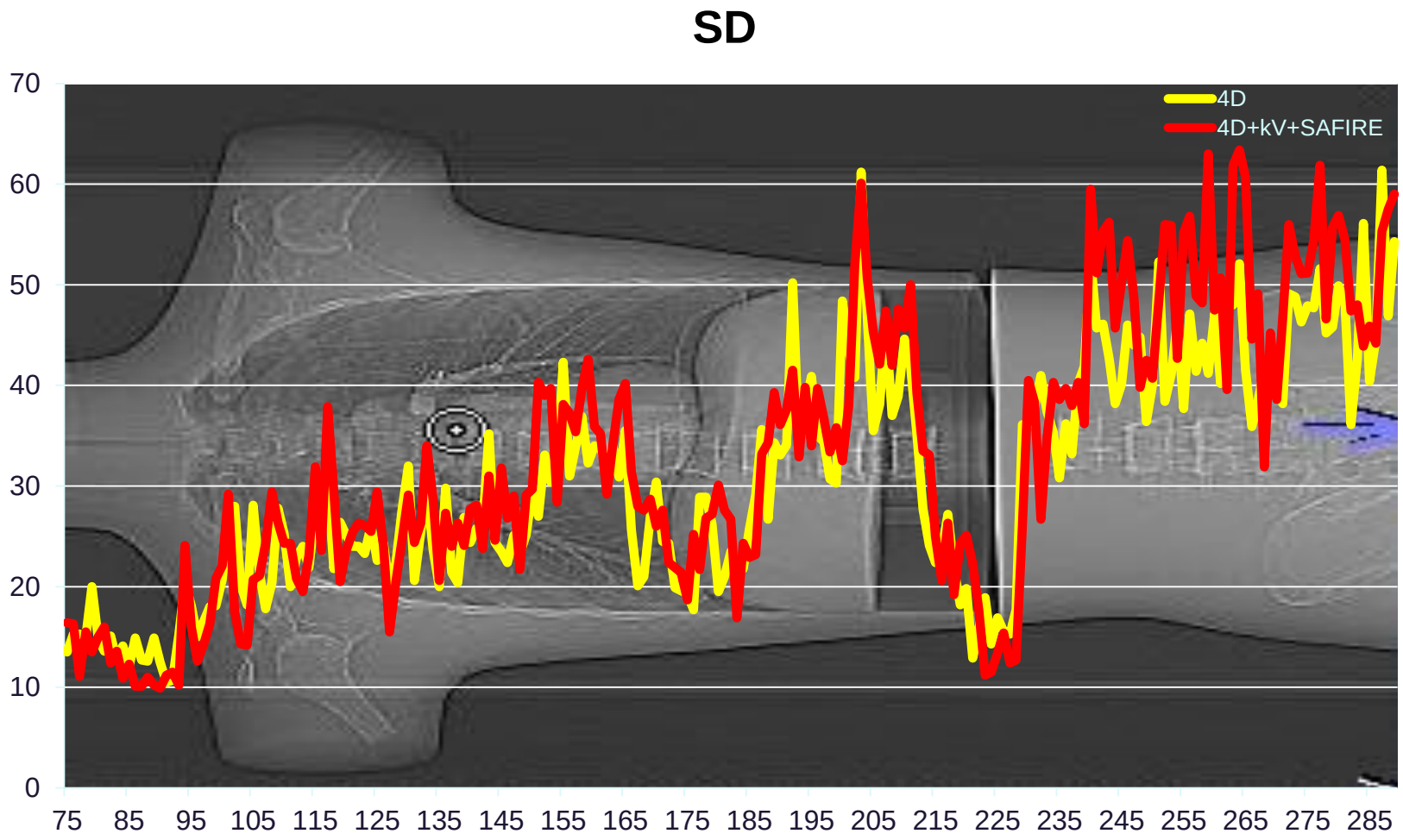


Optimized Selection of X-ray Tube Voltage



Iterative Statistical CT Reconstruction

Combination of 3 Methods for CT Dose Reduction



..Thank you..

E-mail : yhd_1981@naver.com