# Advanced Reconstruction Methods on Philips CT Systems

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CT R&D

# Philips Solution for Advance Reconstruction

**iDose$^{4}$**

***PARADIGM SHIFT***

IMR

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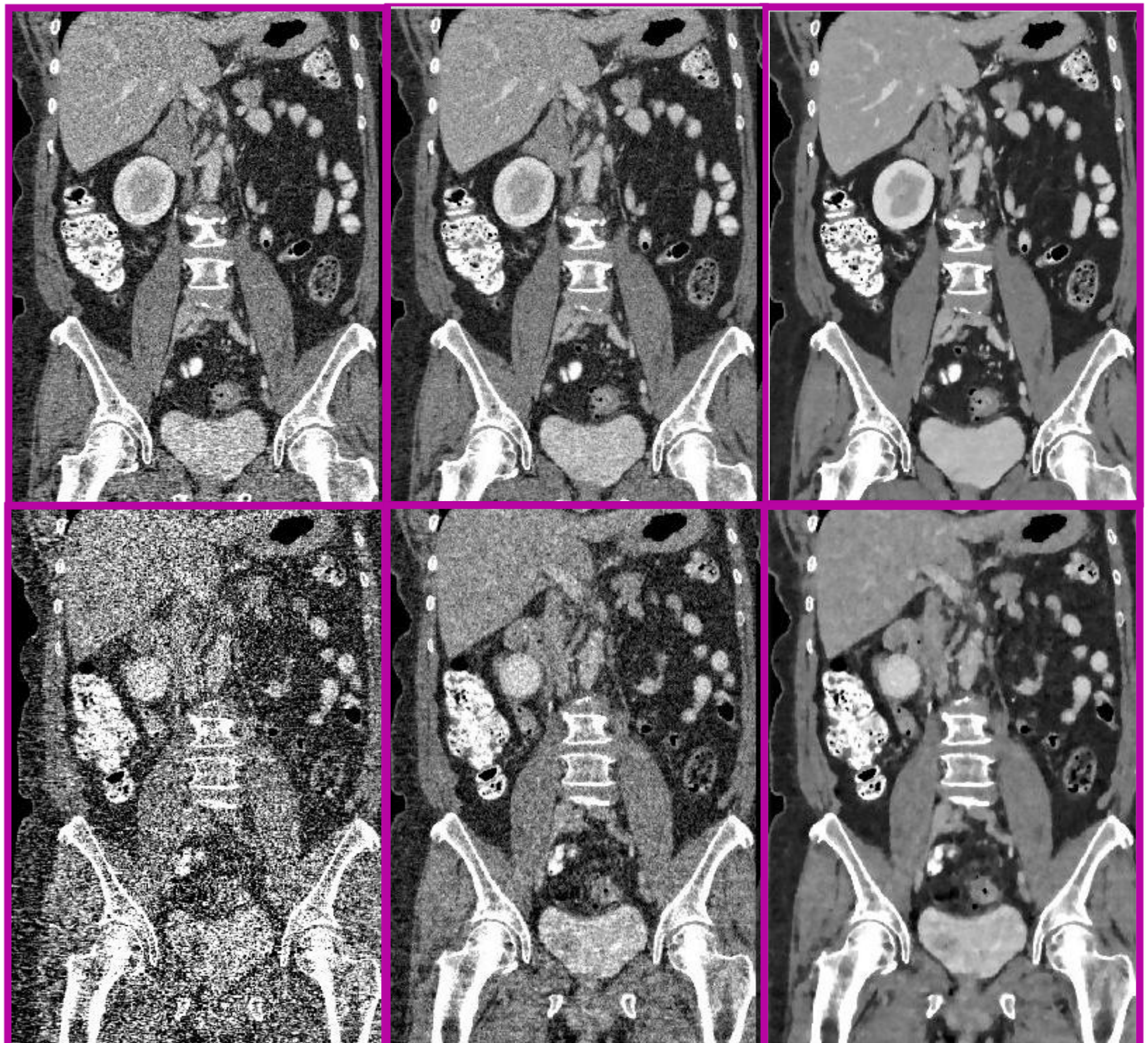
FBP | iDose | IMR

128 mAs

20 mAs



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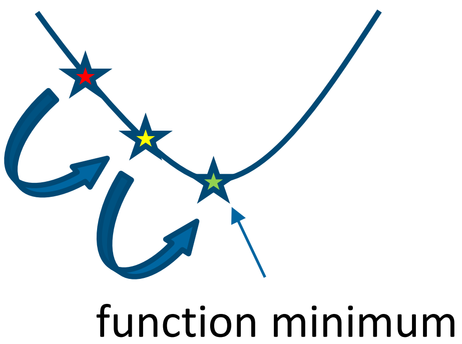
# What is IMR?

- **I**terative **M**odel **R**econstruction
- Formulates image reconstruction as optimization of cost function, F($x$), where $x$ is the image that minimizes F
- Function is solved iteratively because no explicit solution exists

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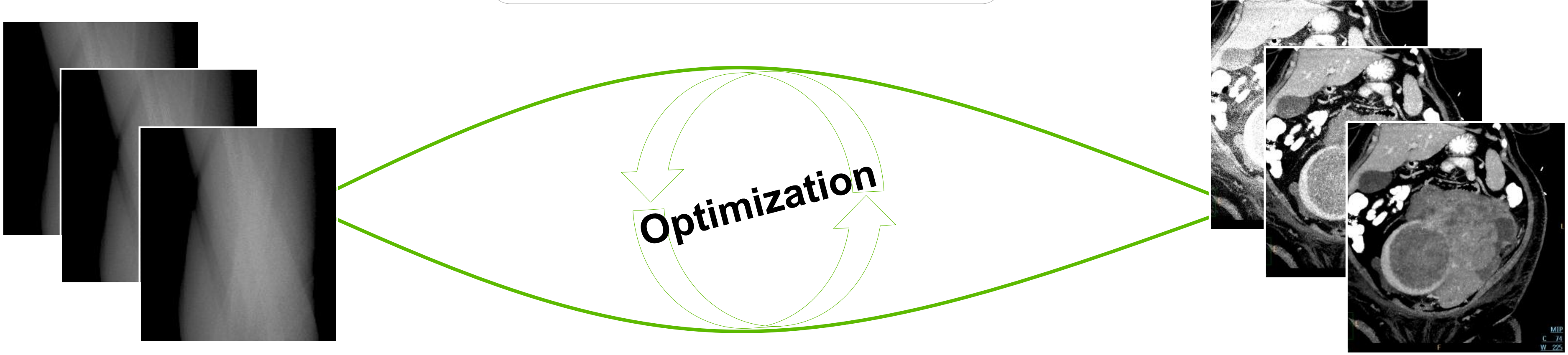
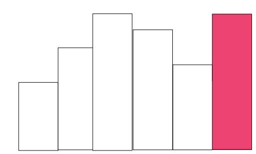
**Cost Function [F($x$)]**




## System Model

Detailed description of system geometry.

## Statistics Model



Representation of ideal measurement of object based on Poisson model of x-ray transport.

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# Cost Function

$$\mathrm{F}(x) = \underbrace{D(x)}_{} + \beta \cdot \underbrace{R(x)}_{}$$

Data fit:
Difference between
estimated and acquired data

Regularization:
Noise penalty

Minimized when

- estimated data most closely matches actual data
- noise is low

Optimization is balance between data fit and noise

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# Cost Function

$$F(x) = D(x) + \beta \cdot R(x)$$

- Defined by the desired image and the starting image
- Desired image is controlled by [redacted] taking into account [redacted] and [redacted]
- Starting image is [redacted] after [redacted] while preserving [redacted]

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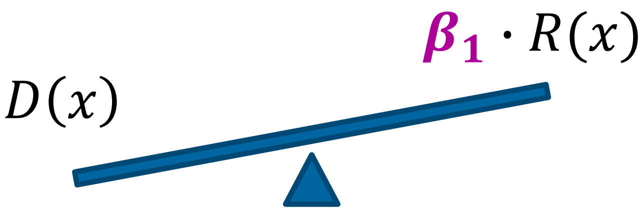
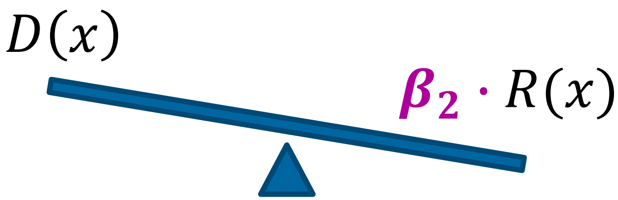
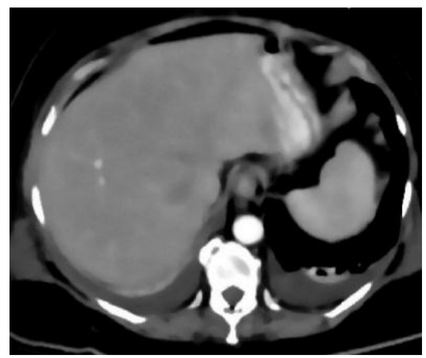
# Noise Constraint

$$F(x) = D(x) + \boldsymbol{\beta} \cdot R(x)$$

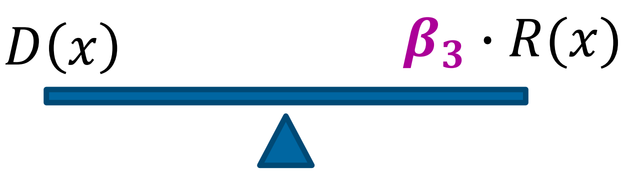



= too noisy



= too smooth




= “just right”

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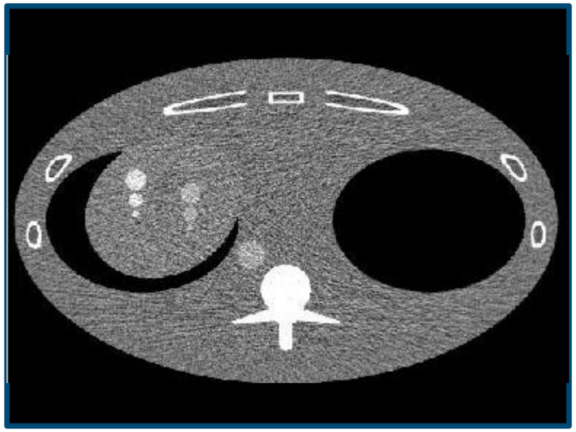
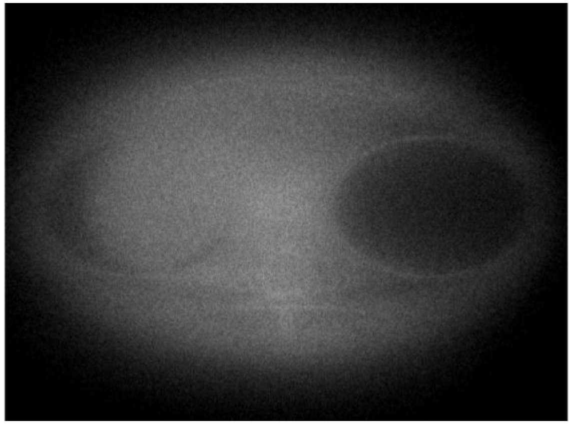
# Noise Modeling

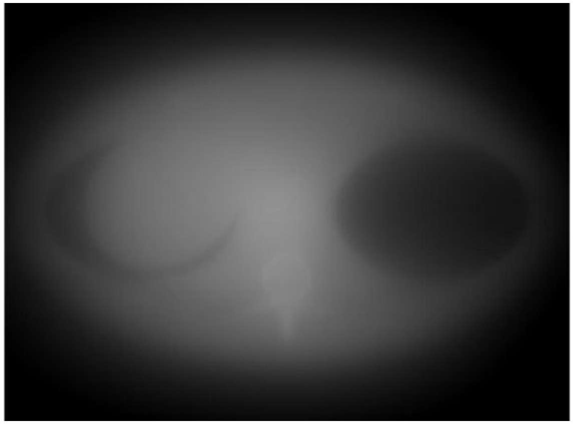
Attenuation Image



True Noise (Monte Carlo)



Noise Map



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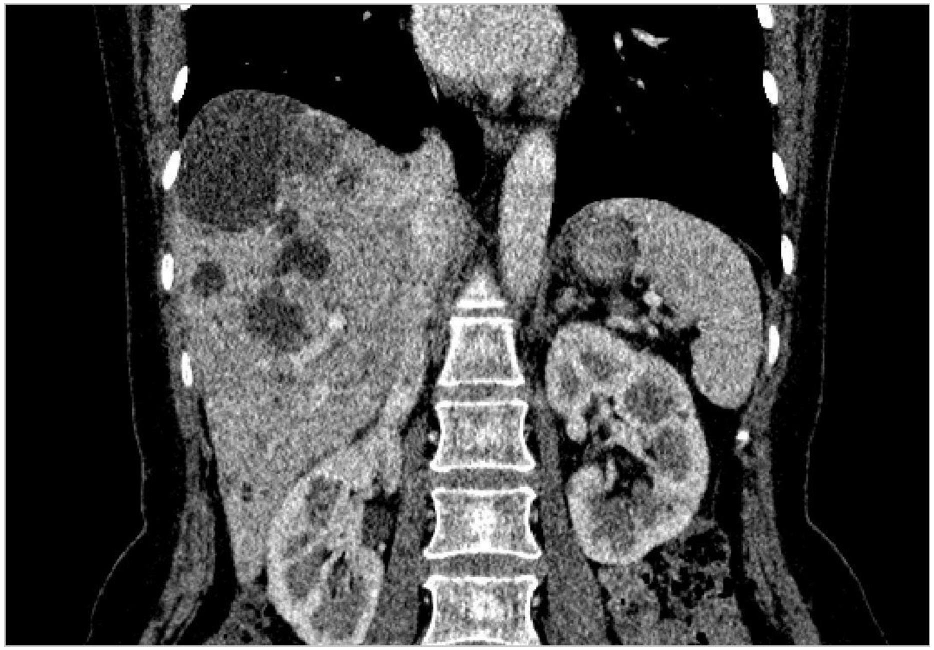
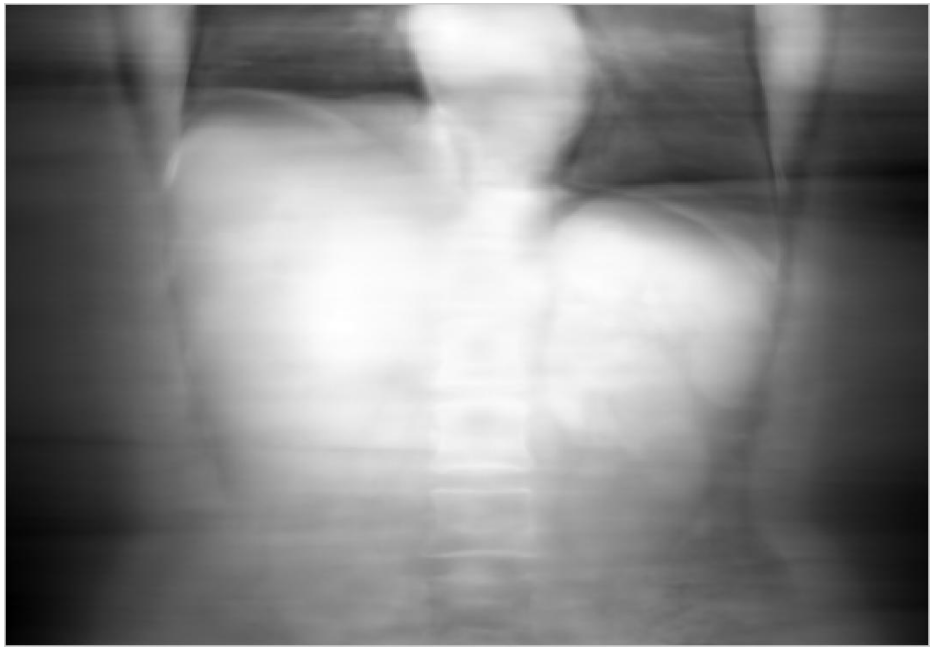
# Noise Modeling

Attenuation Image



Noise Map



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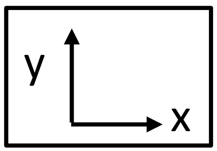
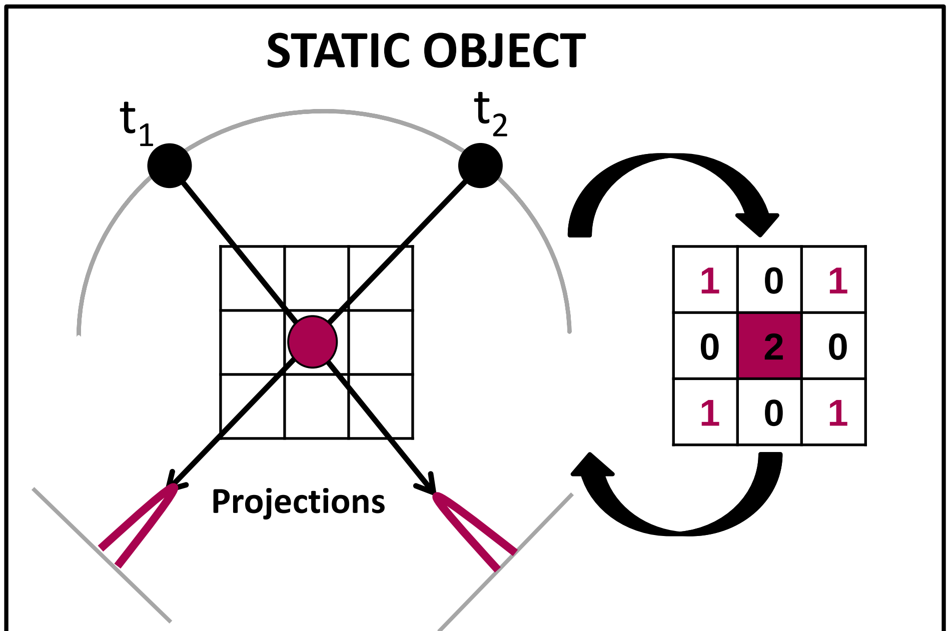
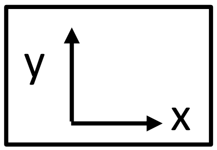
# Static vs. Moving Object

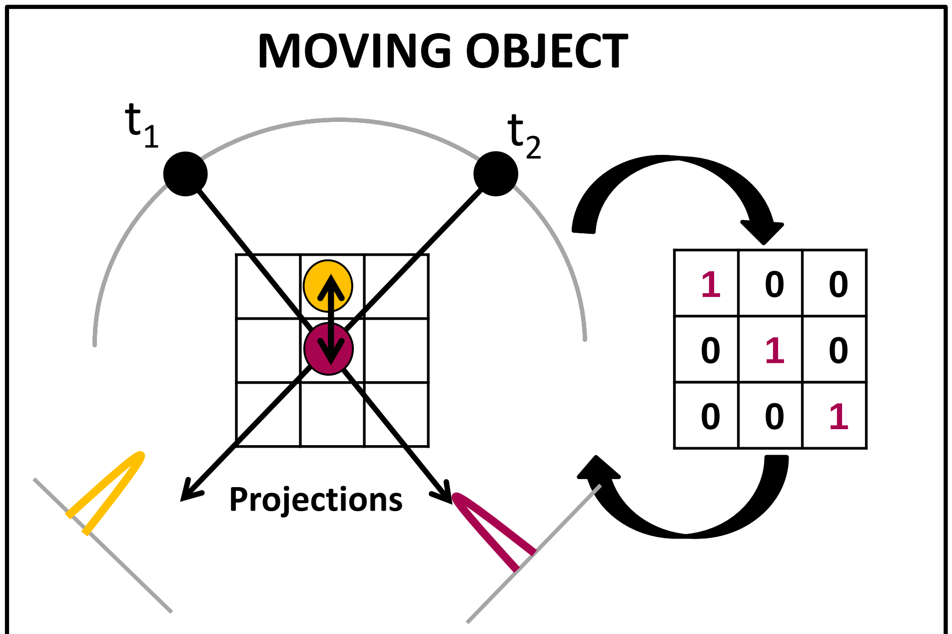



- ✓ **Image matches projections**
- ✓ **Optimization achieved**
- ✓ **High-resolution, low-noise image**

# Static vs. Moving Object




- ✕ **Image DOES NOT match projections**
- ✕ **Optimization NOT achieved**
- ✕ **Image “forced” to match, artifacts**

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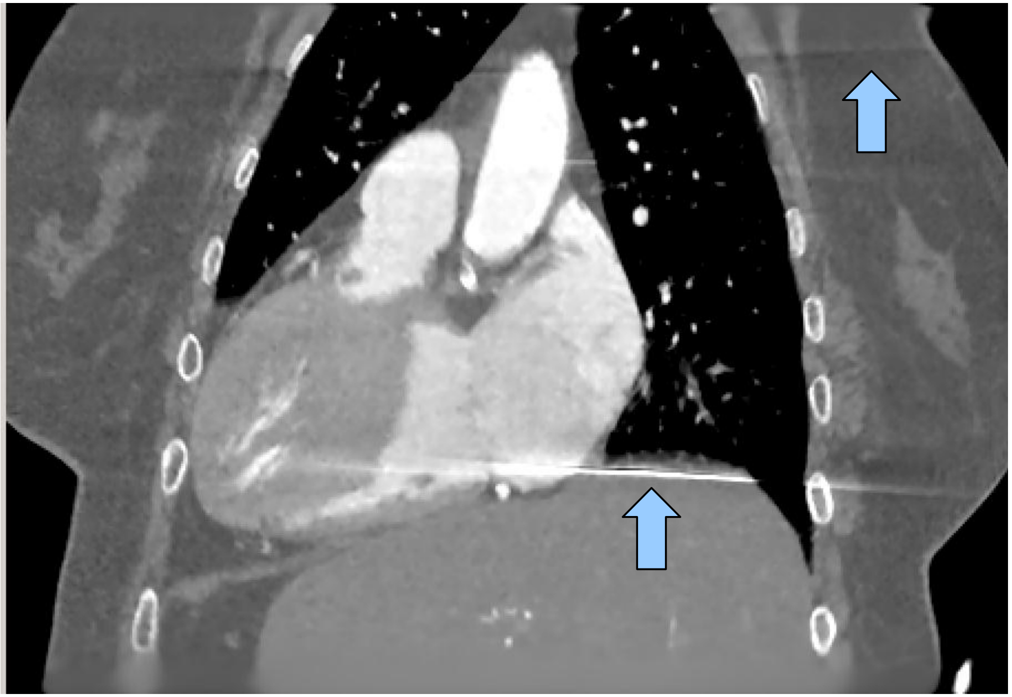
# Motion Sensitivity

- Manifestation of motion on model/knowledge based IR is unpredictable
- May compromise image quality since optimization “forces” data match

IMR w/o
motion compensation



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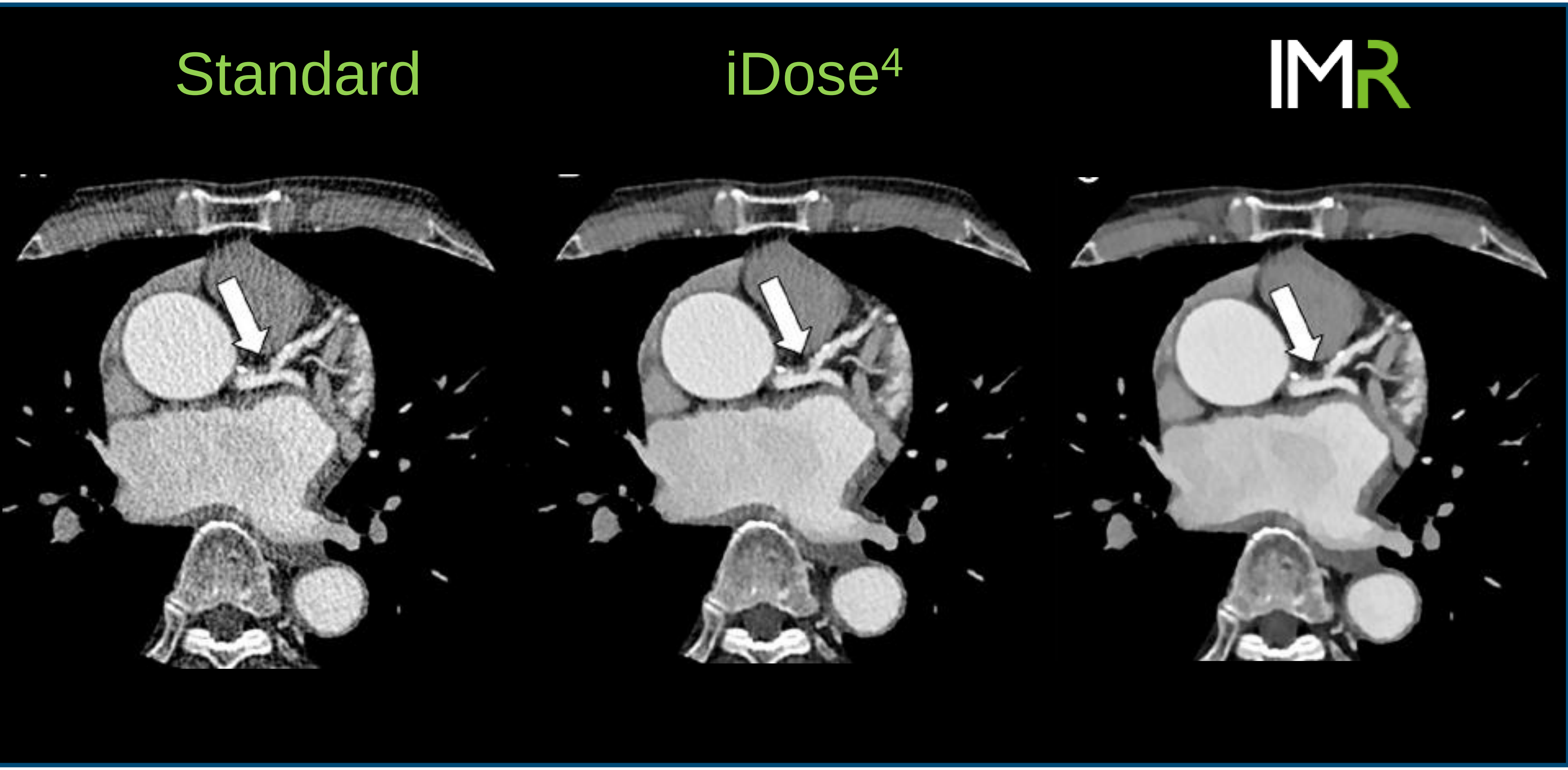
# Cardiac CT




*Yuki et al., JCCT, 2014*

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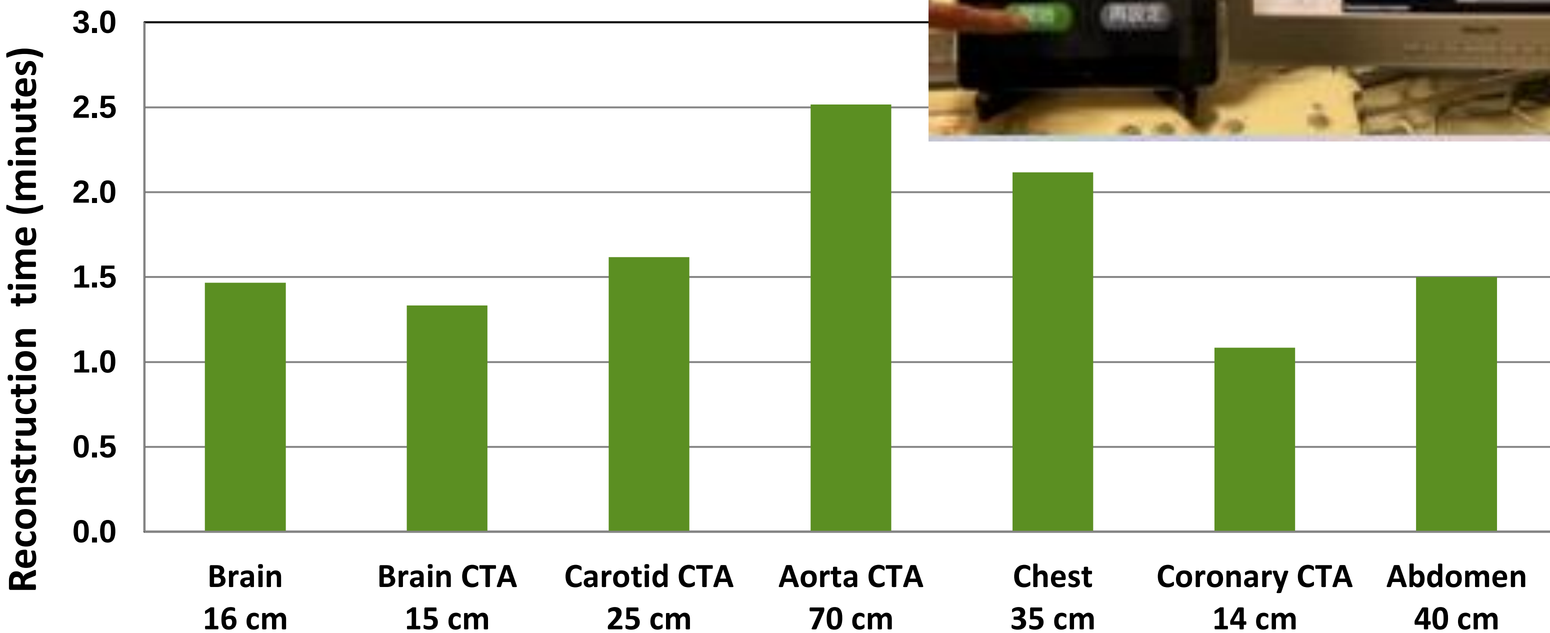
# IMR Reconstruction Times

**Number of Images = 1201**


***Measured on iCT Elite***

# Benefits of IMR

↓ Noise

+

↓ Dose

+

↑ Low Contrast Detectability

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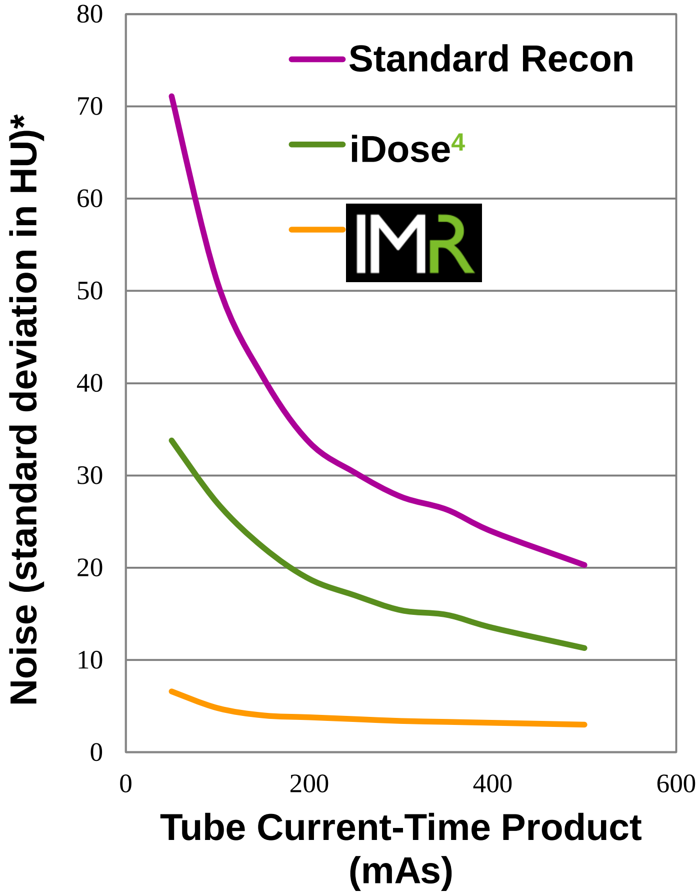
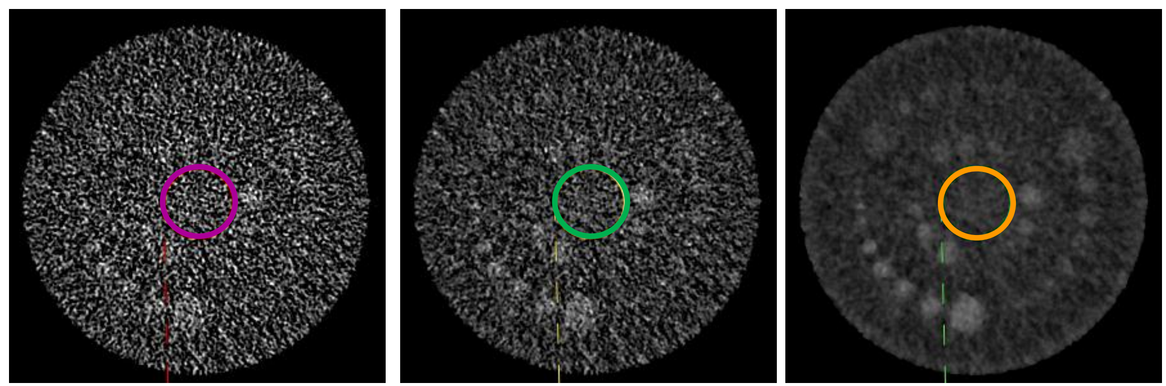
# ↓ Noise




1 mm slice thickness
10 mGy $CTDI_{vol}$

**Standard Recon** | **iDose4** | **IMR**



**SD: 15.4 HU** | **SD: 8.7 HU** | **SD: 1.9 HU**

** Image noise as defined by IEC standard 61223-3-5. Assessed using Reference Body Protocol on a CATPHAN phantom.*

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↓ Noise + ↓ Dose + ↑ LCD

# Task-Based Image Quality Assessment

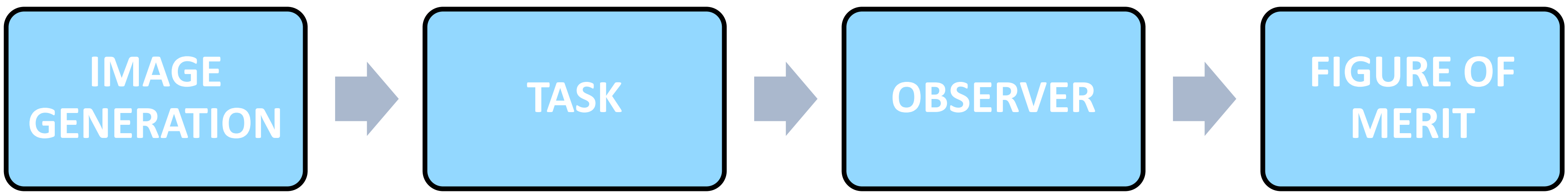


**IMAGE GENERATION**

- MITA Test Phantom

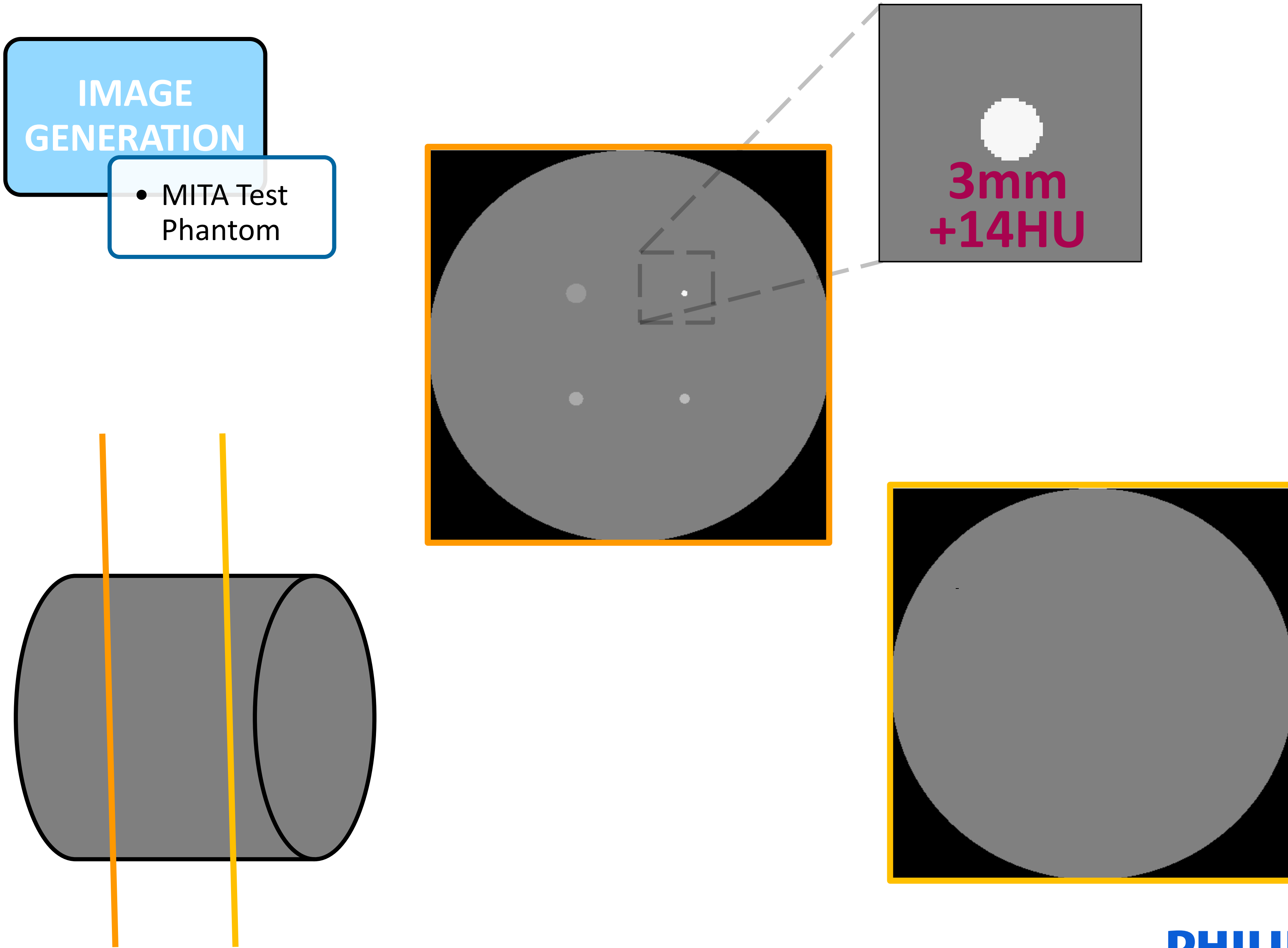
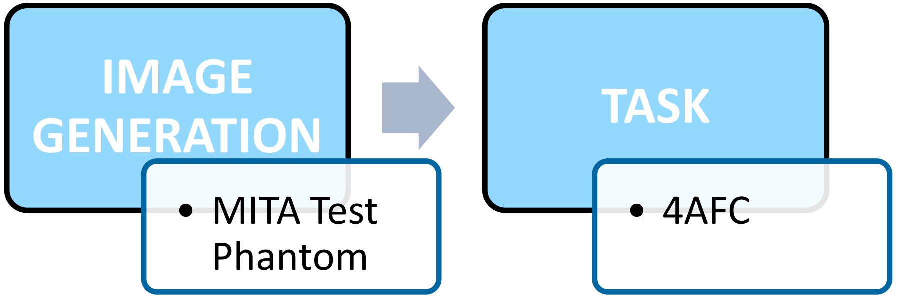


**IMAGE GENERATION**

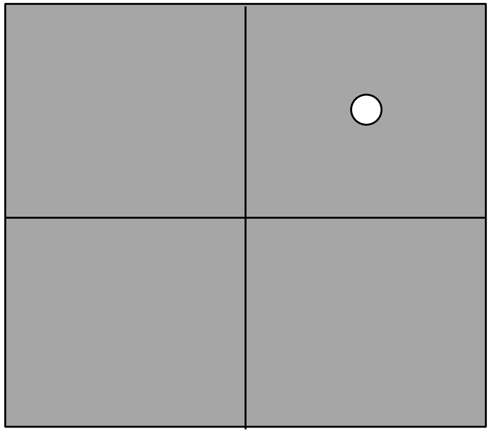
- MITA Test Phantom

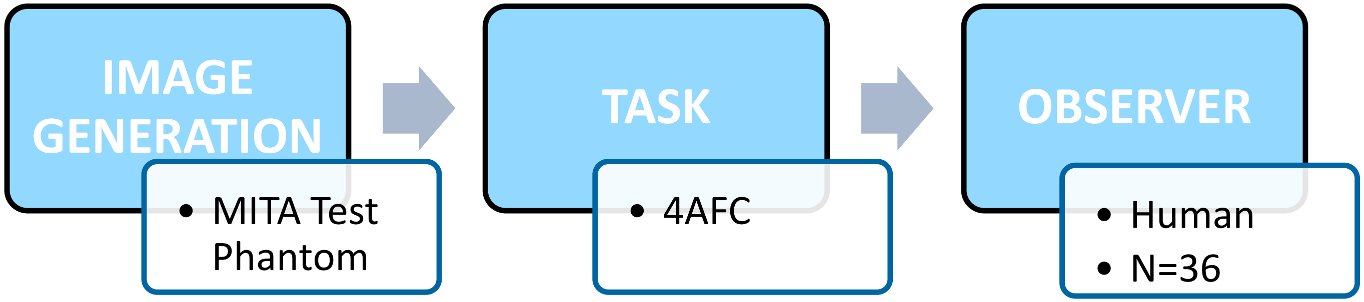
- Scanned 200x (100x @ each dose)
- Reconstructed 200x

| | | |
|---|---|---|
| **Mode** | Helical | |
| **Gantry Rotation Time** | 750 ms | |
| **Beam Collimation** | 64x 0.625 mm | |
| **Pitch** | 0.6 | |
| **Tube Potential** | 120 kV | |
| **Tube Current-Time Product** | 153 mAs | 31 mAs |
| **$CTDI_{vol}$** | 10 mGy | 2 mGy |
| **Reconstruction algorithm** | FBP | IMR |
| **Slice Thickness** | 0.8 | |
| **Slice Increment** | 0.4 | |




- Created 200 sets of 4 images (100 @ each dose level)
  - Each image with same dose and recon algorithm
  - 1 image → 3 mm pin
    3 images → uniformity section
  - Random position of image containing pin
- Task = choose image w/ pin






- 36 human observers
- Each observer executed 100 trials per dose level

TOTAL TRIALS PER DOSE LEVEL = 3,600

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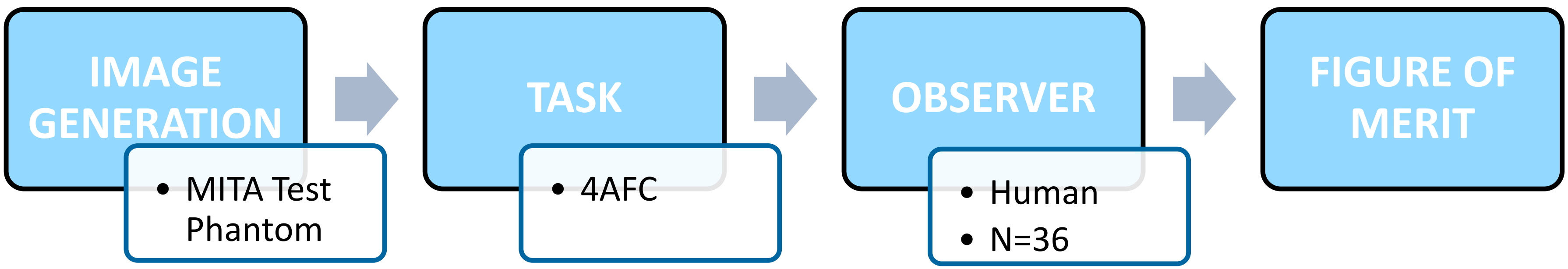
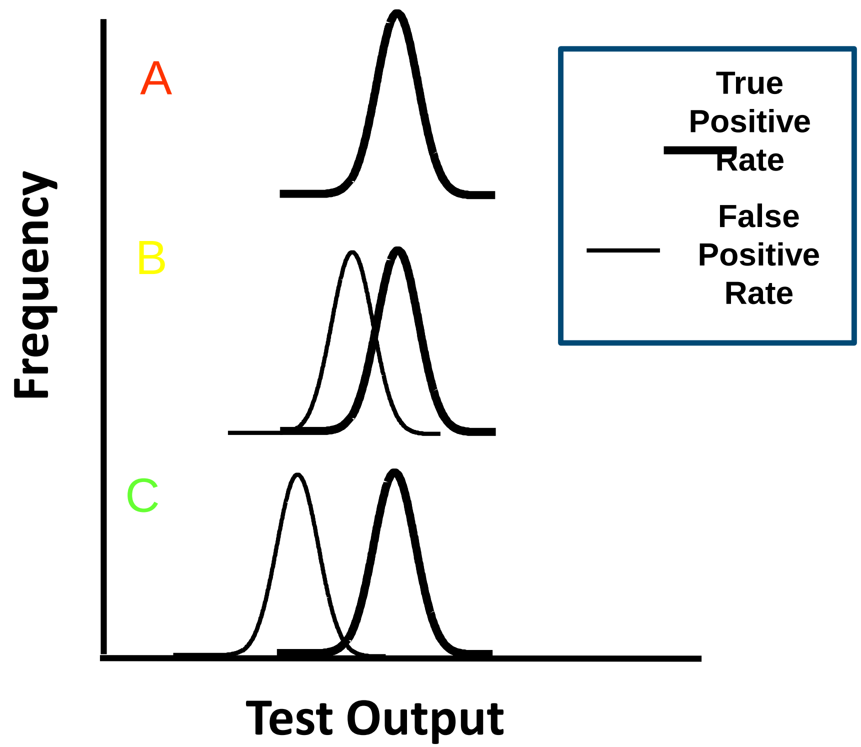



# Receiver Operating Characteristic (ROC)



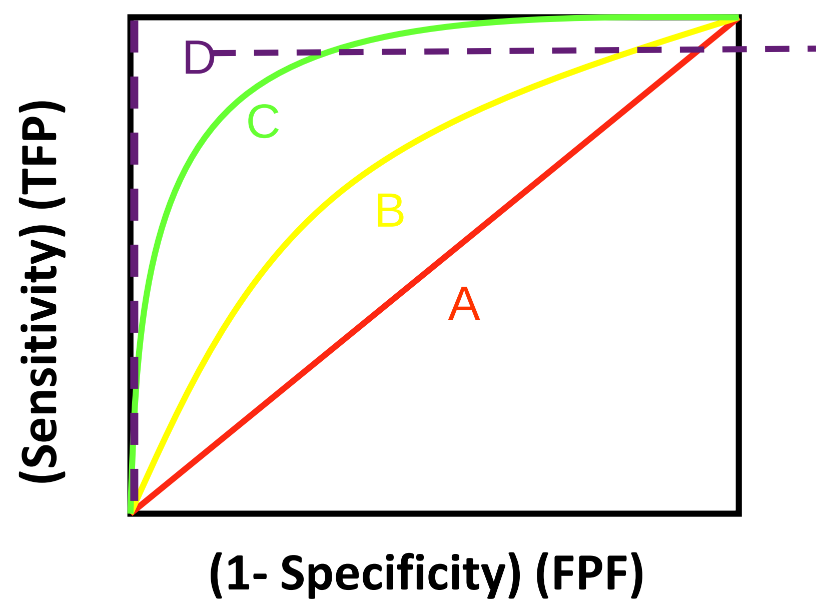




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**IMAGE GENERATION** → **TASK** → **OBSERVER** → **FIGURE OF MERIT**

- IMAGE GENERATION: MITA Test Phantom
- TASK: 4AFC
- OBSERVER: Human; N=36
- FIGURE OF MERIT: Detectability Index, d’

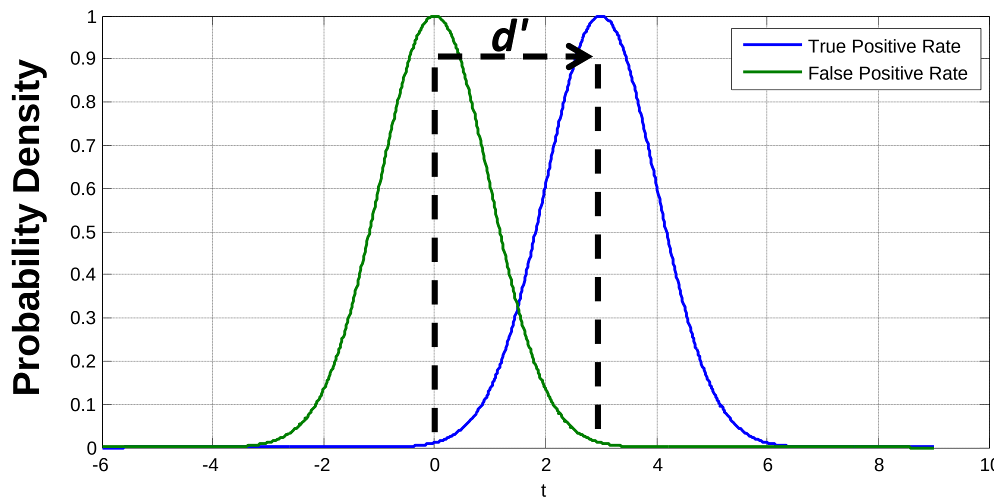
# Detectability Index (d’)

$$d' = \frac{\bar{t}_{TP} - \bar{t}_{FP}}{\sigma}$$

$\bar{t}_{TP}$ Mean of *measurement* of signal present

$\bar{t}_{FP}$ Mean of *measurement* of signal absent

$\sigma$ Standard deviation, assumed same for both distributions




*Burgess, Med Phys, 1995*

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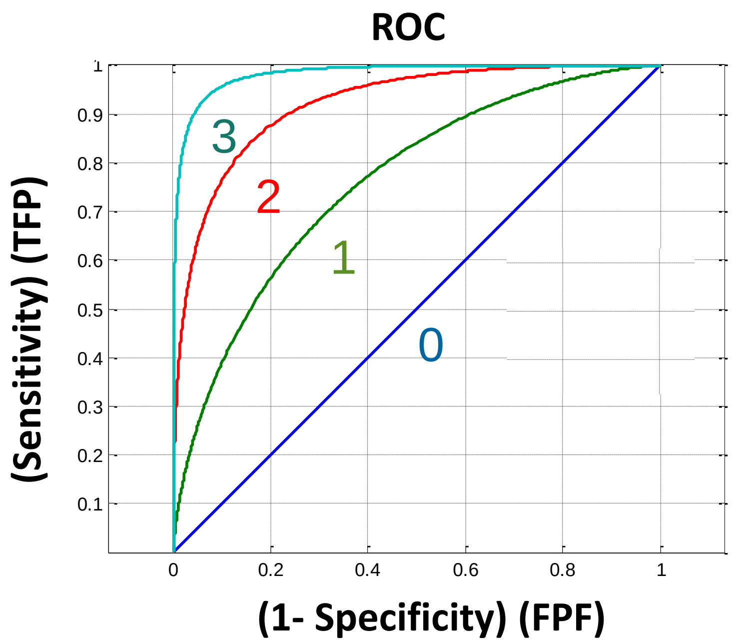
**IMAGE GENERATION** → **TASK** → **OBSERVER** → **FIGURE OF MERIT**

- **IMAGE GENERATION**
  - MITA Test Phantom
- **TASK**
  - 4AFC
- **OBSERVER**
  - Human
  - N=36
- **FIGURE OF MERIT**
  - Detectability Index, d’

| Percent Correct | d’ | AUC |
|---|---|---|
| 0.25 | 0 | 0.50 |
| 0.55 | 1 | 0.76 |
| 0.82 | 2 | 0.92 |
| 0.96 | 3 | 0.98 |




d’ = 0 → Unable to distinguish images with low contrast object *present* from image with low contrast object *absent*

d’ = ∞ → Always able to distinguish image with low contrast object *present* from image with low contrast object *absent*

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# ↓ Noise + ↓ Dose + ↑ LCD

**IMAGE GENERATION**
- MITA Test Phantom

**TASK**
- 4AFC

**OBSERVER**
- Human
- N=36

**FIGURE OF MERIT**
- Detectability Index, d’

| | Median % Correct | Median d’ | $CTDI_{vol}$ |
|---|---|---|---|
| FBP | 50% | 0.821 | 10 mGy |
| IMR | 70% | 1.475 | 2 mGy |

↑ 80% ↓ 80%

# Benefits of IMR

↓ Noise 70-83%

+

↓ Dose 60-80%

+

↑ Low Contrast Detectability 43-80%

*In clinical practice, use of IMR may reduce CT patient dose depending on the clinical task, patient size, anatomical location, and clinical practice. A consultation with a radiologist and physicist should be made to determine appropriate dose to obtain diagnostic image quality for particular clinical task.*

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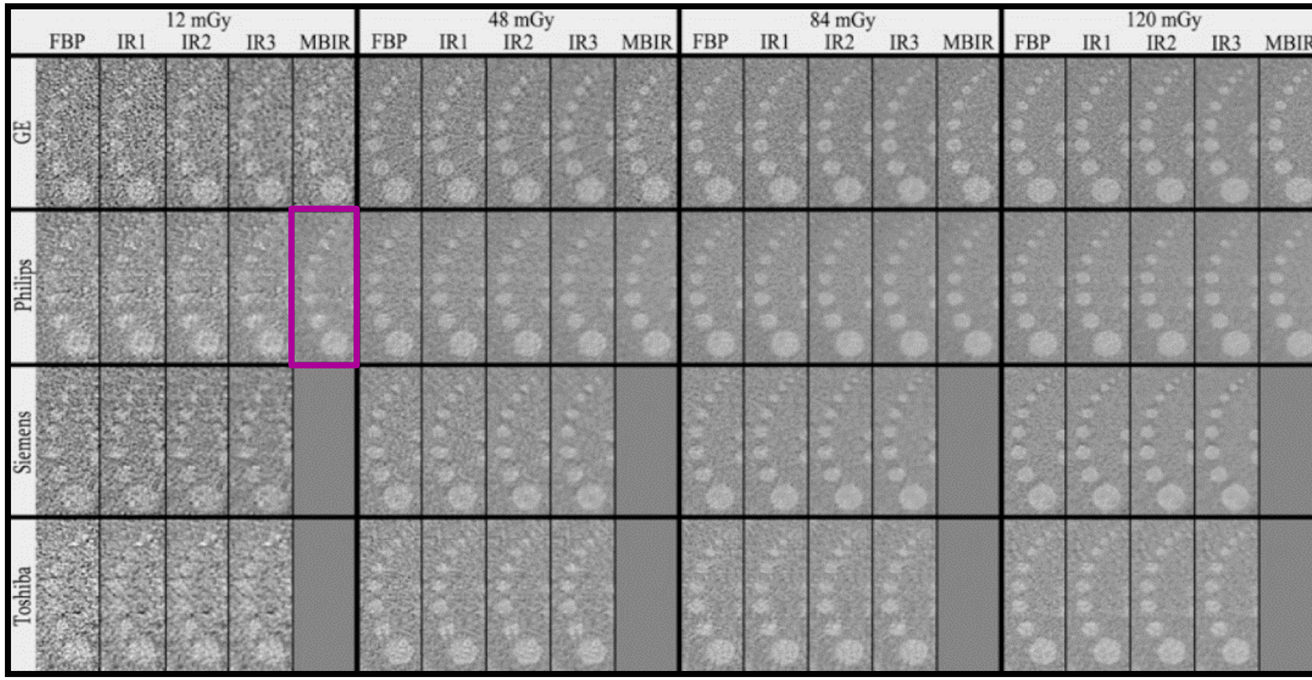
# Image Quality Improvement with IMR

IMR provided

- Lowest noise
- Best low-contrast detectability, including at the lowest dose
- Improved resolution and lowered noise simultaneously




*L¨ove A, et al. Six iterative reconstruction algorithms in brain CT: a phantom study on image quality at different radiation dose levels. Br J Radiol 2013; 86:20130388.*

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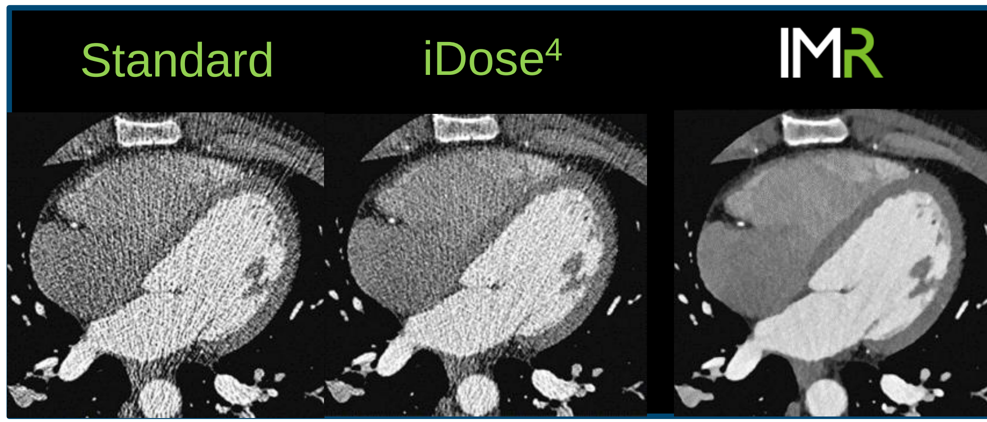
# Low-kVp Made Routine with IMR

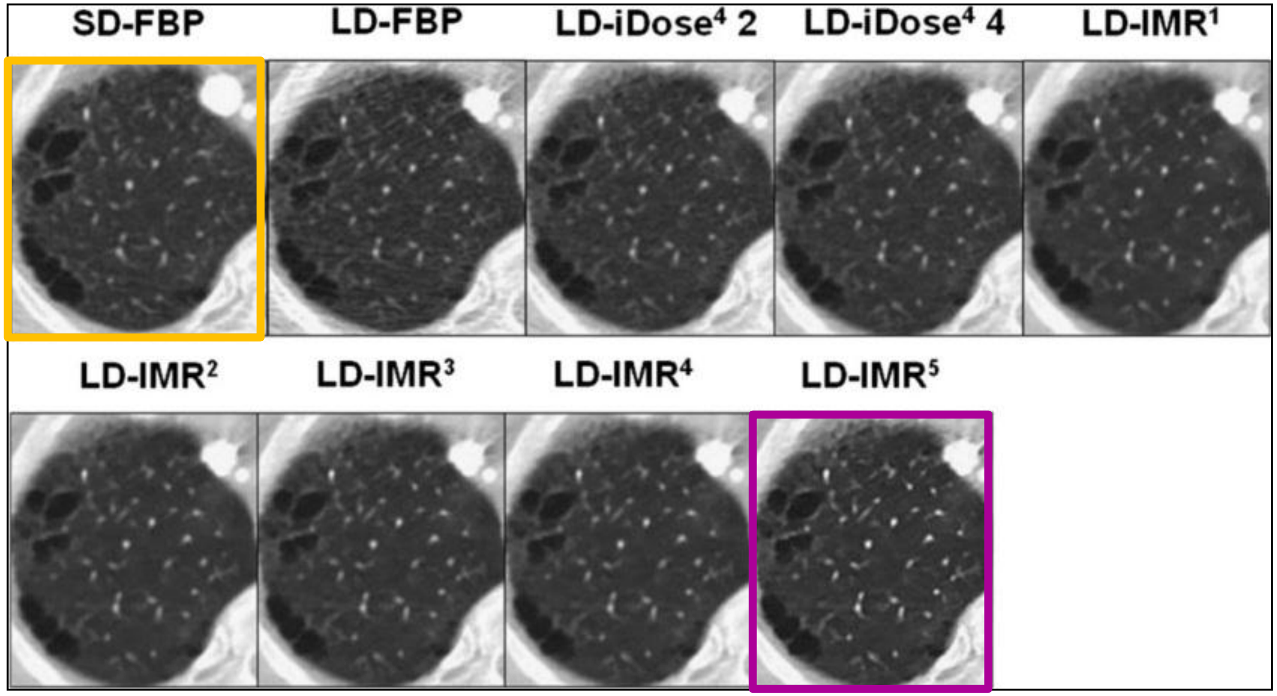
**Table 2**
Qualitative assessment of image quality.

| | Standard | iDose4 | IMR | *p-value* |
|---|---|---|---|---|
| Image noise | 2.5 ± 0.6 | 3.5 ± 0.6 | 4.6 ± 0.6 | <0.01* |
| Streak artifact | 2.4 ± 0.5 | 3.4 ± 0.5 | 4.5 ± 0.5 | <0.01* |
| Vessel sharpness | 2.9 ± 0.5 | 3.8 ± 0.7 | 4.4 ± 0.6 | <0.01* |
| Overall image quality | 2.7 ± 0.5 | 3.8 ± 0.5 | 4.8 ± 0.4 | <0.01* |




***Oda S. et al, Iterative model reconstruction: Improved image quality of low-tube-voltage prospective ECG-gated coronary CT angiography images at 256-slice CT, Eur J Radiol (2014)***

# Sub-mSv Imaging for Nodule Assessment with IMR




**Conclusions:** Sub-mSv IMR improves delineation of lesion margins compared to standard-dose FBP and sub-mSv iDose$^4$.

*Khawaja R. et al, CT of Chest at <1 mSv: An Ongoing Prospective Clinical Trial of Chest CT at Sub-mSv Doses with IMR and iDose$^4$ , JCAT 2014;38: 613–619*

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# Improved Detection of PE with IMR

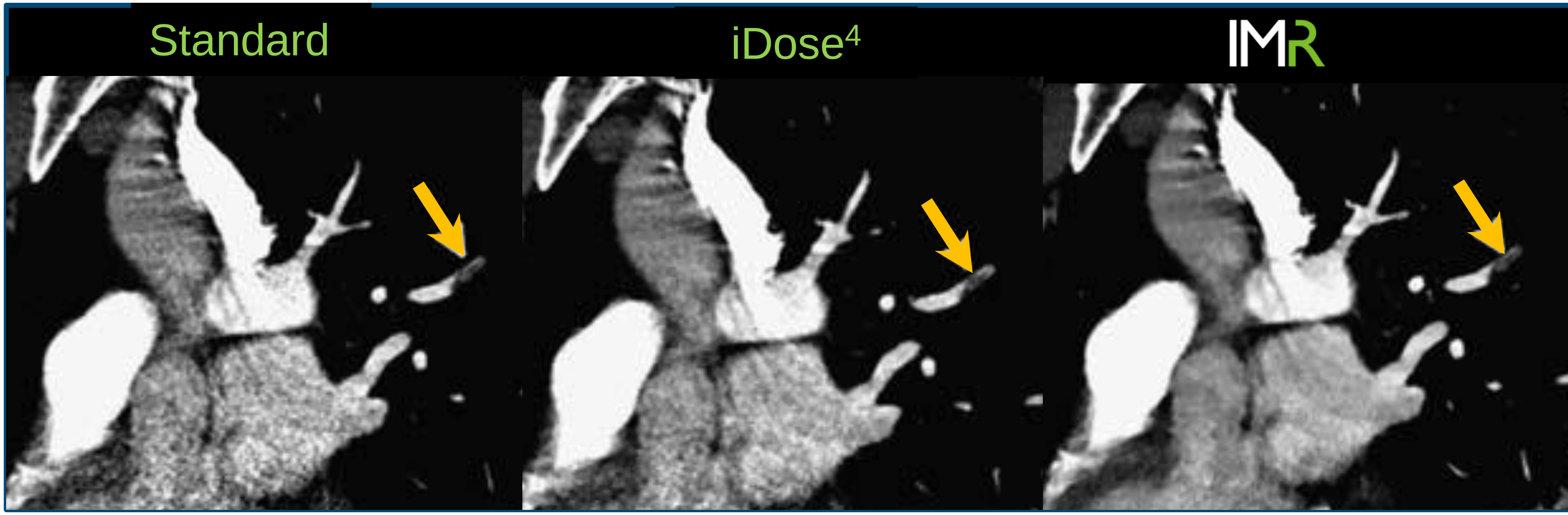


**TABLE 3.** Pooled Reader Detection and Sensitivity in Relation to Number and Location of Pulmonary Emboli

| | Isolated SS (n = 77) | Isolated Seg (n = 21) | Isolated Total (n = 98) | Multiple SS (n = 7) | Multiple Seg (n = 49) | Multiple Total (n = 56) | Total (n = 154) |
|---|---|---|---|---|---|---|---|
| FBP [n (%)] | 49 (63.6) | 15 (71.4) | 64 (65.3) | 7 (100) | 46 (93.9) | 53 (94.6) | 117 (76.0) |
| HIR [n (%)] | 50 (64.9) | 16 (76.2) | 66 (67.3) | 7 (100) | 48 (98) | 55 (98.2) | 121 (78.6) |
| MBIR [n (%)] | 56 (72.7) | 16 (76.2) | 72 (73.5) | 7 (100) | 48 (98) | 55 (98.2) | 127 (82.5) |
| rANOVA (*P*) | **0.037** | 0.356 | **0.033** | 1 | 0.384 | 0.384 | **0.01** |
| FBP-HIR (*P*) | 0.689 | | 0.457 | | | | 0.103 |
| FBP-MBIR (*P*) | **0.018** | | **0.033** | | | | **0.016** |
| HIR-MBIR (*P*) | 0.078 | | 0.078 | | | | **0.045** |

*Kligerman. et al, Detection of PE on CT: Improvement using Model-Based Iterative Reconstruction compared with FBP and Iterative Reconstruction. J* Thorac Imaging 2015;30:60–68

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# IMR Highlights

## Proven benefits

Rigorous human observer studies evidence simultaneously lowering noise, dose, and improving low contrast detectability

## Fast reconstruction times

Majority of reference protocols reconstructed in < 3 min

## Model-based solution for cardiac

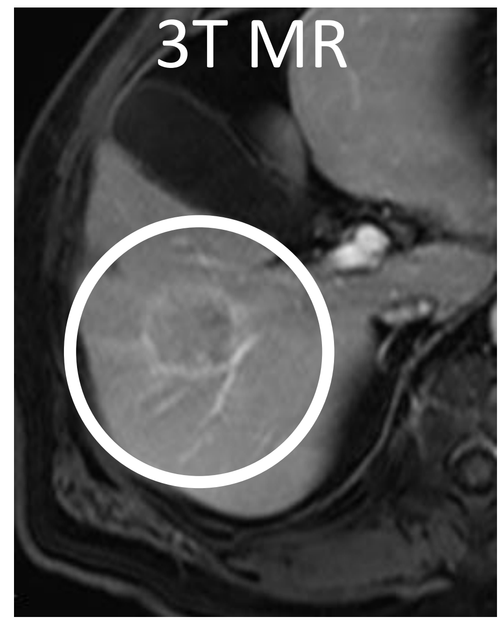
IMR is currently only model-based iterative algorithm available for cardiovascular image reconstrcution

## Installs

250 sites with IMR by end of 2015

## Scientific papers

30 peer-reviewed publications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