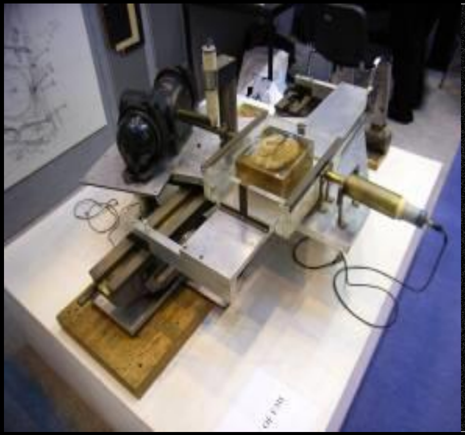
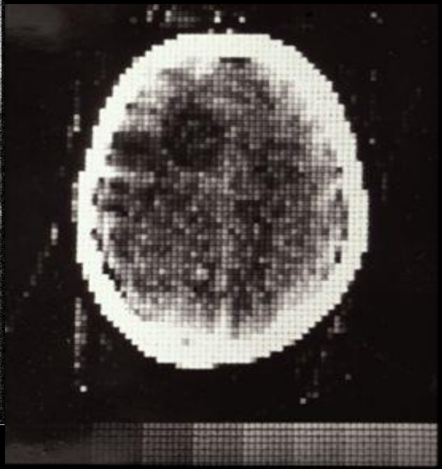
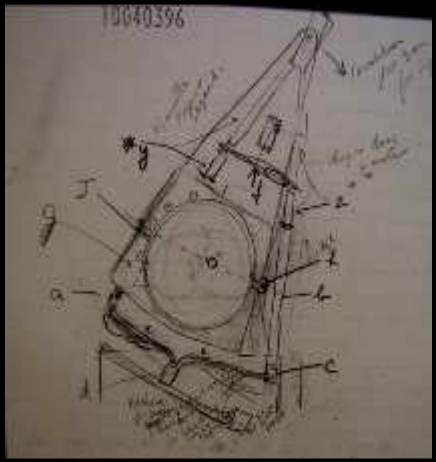
Iterative Reconstruction





Richard Andrew
CT Clinical Science Group

CT was invented in 1972 by British engineer Godfrey Hounsfield of EMI Laboratories, England



2

The first CT scanner developed by Hounsfield in his lab at EMI took several hours to acquire the raw data for a single scan or "slice" and took days to reconstruct a single image from this raw data.

The reconstruction process used was that of **Iterative reconstruction**

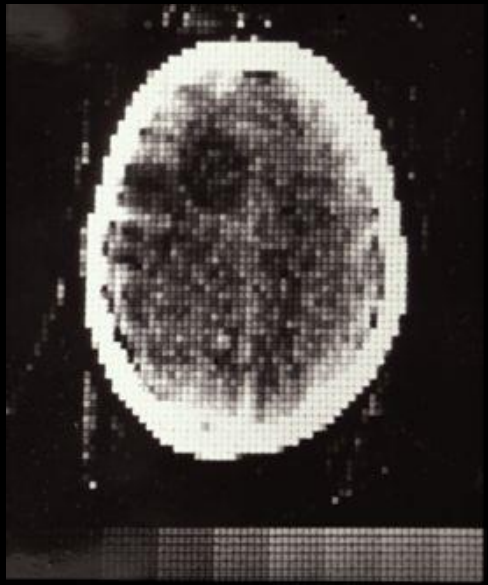
3

The first prototype scanner had:

80 x 80 matrix
Dual slice system (2 x 10mm)
5 minutes to acquire each scan
5 minutes to reconstruct each image .

The reconstruction process used was that of **filtered back projection**

4



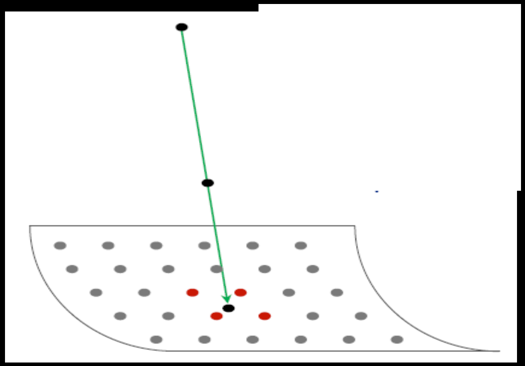
Following the first clinical scan at Atkinson Morley Hospital, London 1971, the patient with the suspected frontal lobe tumour was operated on. The surgeon performing the operation is reported to have remarked that:
"it looks exactly like the picture.”

5

The first commercial scanner to be installed, the EMI Head CT Scanner was at the Manchester Royal Infirmary

Filtered Back Projection reconstruction

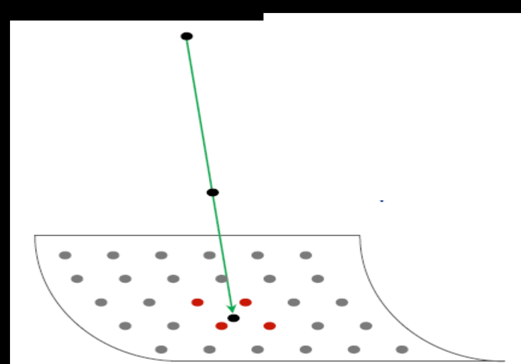
Focal spot = point
Detector = point
Voxel = point
X ray Beam = line
Constant noise sample



Simple fast calculation
High noise / dose
Spatial OR Contrast Resolution

Statistical (Hybrid) Iterative Reconstruction

Focal spot = point
Detector = point
Voxel = point
X ray Beam = line
Statistical noise model

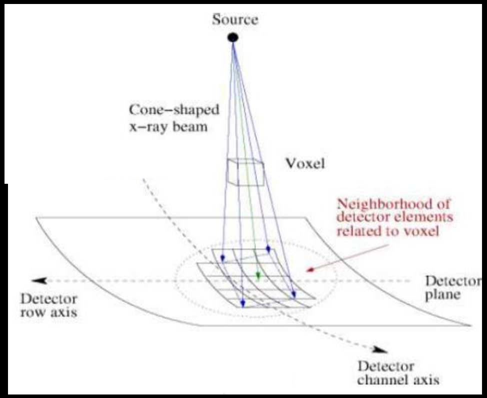


Relatively fast calculation
Lower noise/ dose
Spatial OR Contrast Resolution

Philips: iDose
GE: ASIR
Siemens: SAFIRE/ Admire
Canon: ADIR 3D

Model Based Iterative reconstruction

Focal spot = real
Detector = real
Voxel = cube
X ray Beam = real
Statistical noise model
System model



Philips: iMR

GE: ASIR V

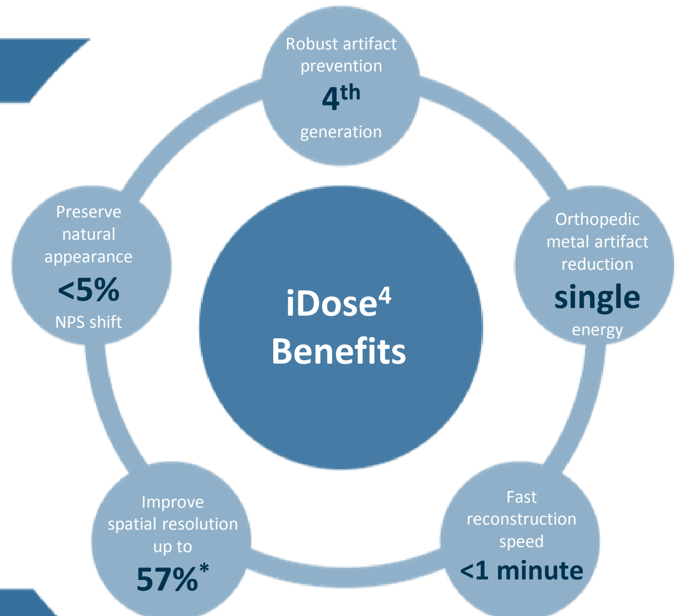
Canon: FIRST

Complex slow calculation
Low noise / dose
High Spatial AND Contrast Resolution

iDose^4 Premium Package option

Broad range of clinical benefits

- High-resolution **pulmonary** imaging
- Low-noise **bariatric** imaging
- Low-noise **neuro** imaging
- High-resolution **coronary** imaging
- High-resolution low-dose **pediatric** imaging



- **Low-dose** imaging with **low noise**
- Low-artifact **fast-recon trauma** imaging
- **Low-kVp** across a broad range of patients

*Ingenuity CT systems only

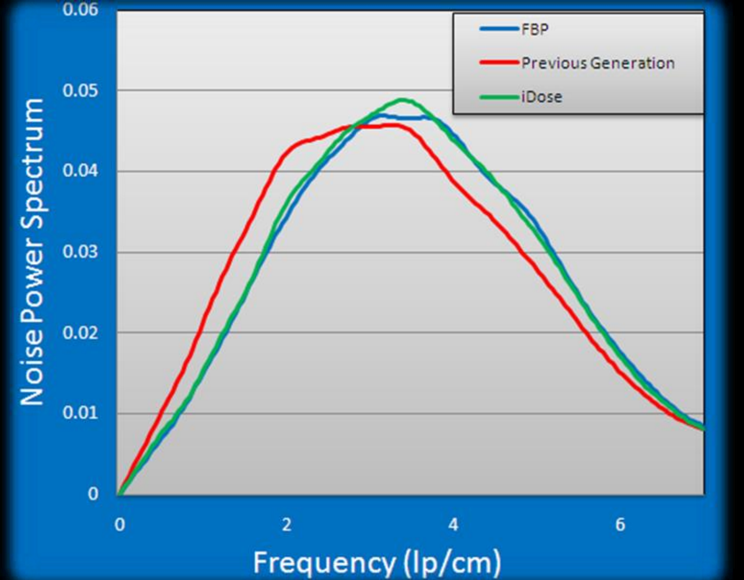
PHILIPS

Up to **80%** less dose with equivalent diagnostic image quality

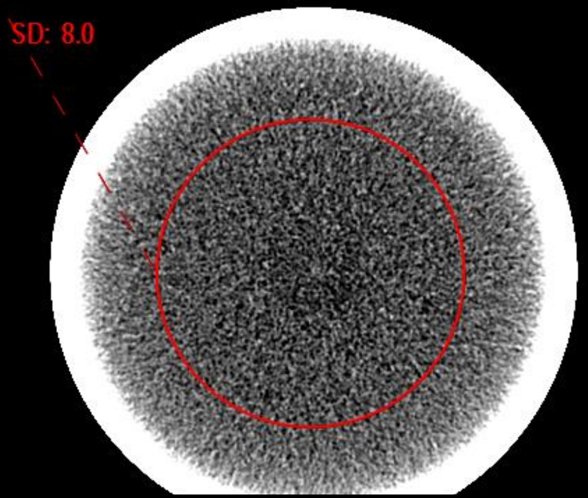
Up to **50%** less dose with up to **35%** improvement in spatial resolution

Up to **68%** improvement in spatial resolution at the same dose

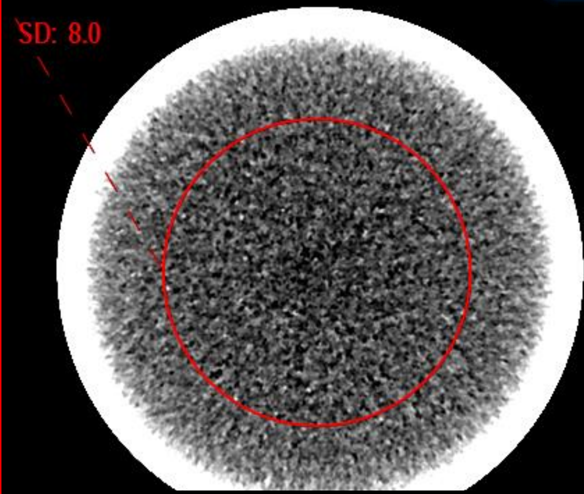
iDose^4: Natural Appearance



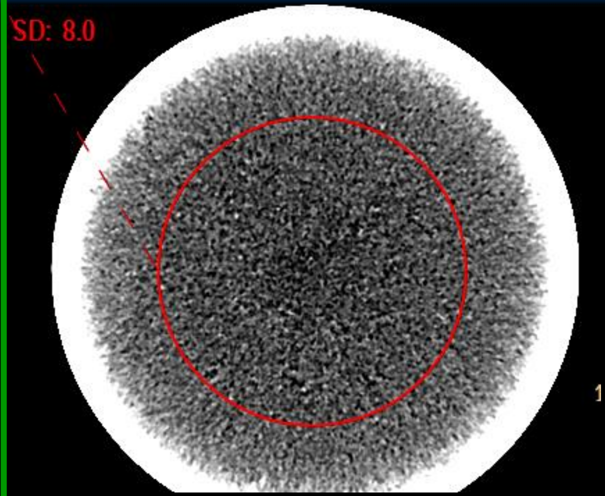
iDose^4 preserves NPS and Image looks NATURAL



Filtered Back-Projection
Routine Dose



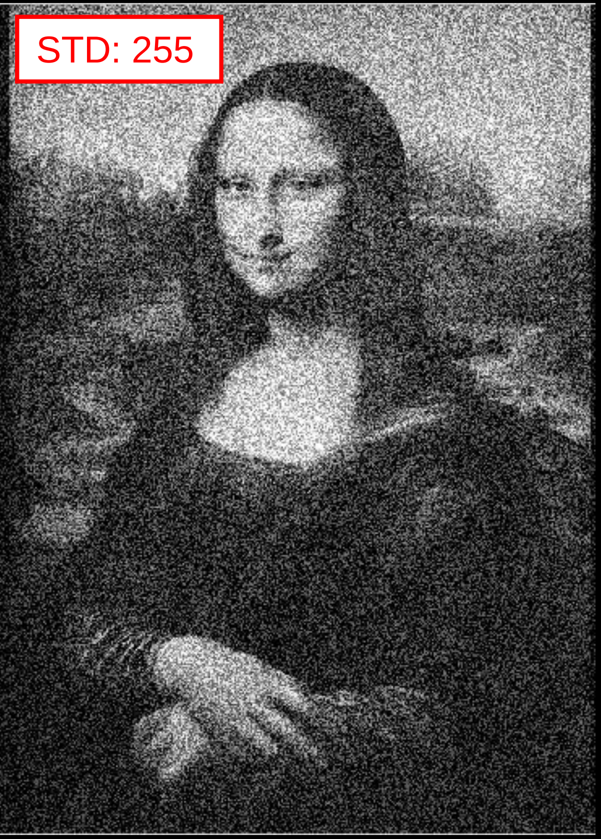
Basic Iterative Reconstruction
Low Dose after noise reduction
NPS shift= 19%

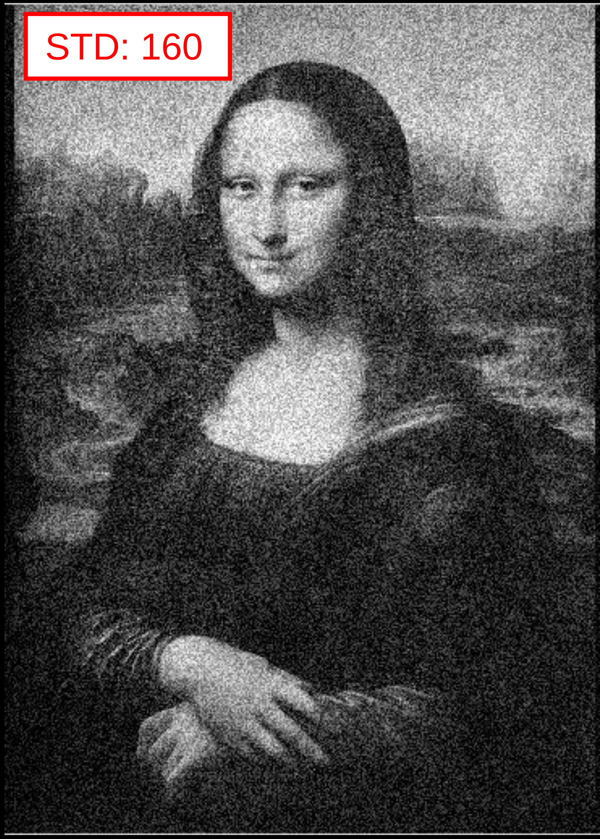


iDose^4
Low Dose after noise reduction
NPS shift $\leq$ 5%

With Noise Power Spectrum shift, image can look "PLASTIC"

Natural Appearance Simulation





Original Image
No noise removal

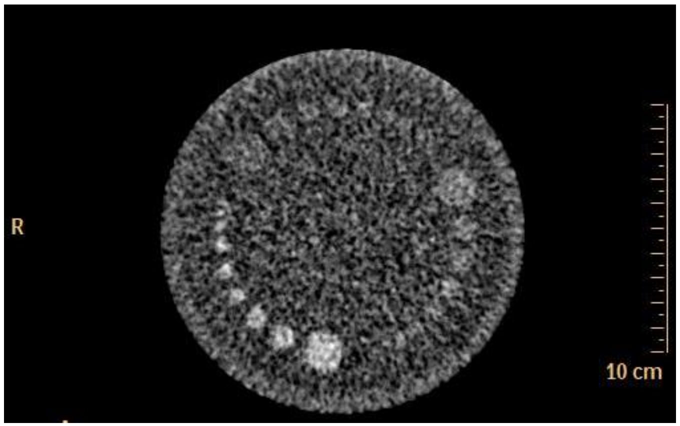
Noise Removal
Shifting NPS to low frequency

Noise Removal
No shift in frequency

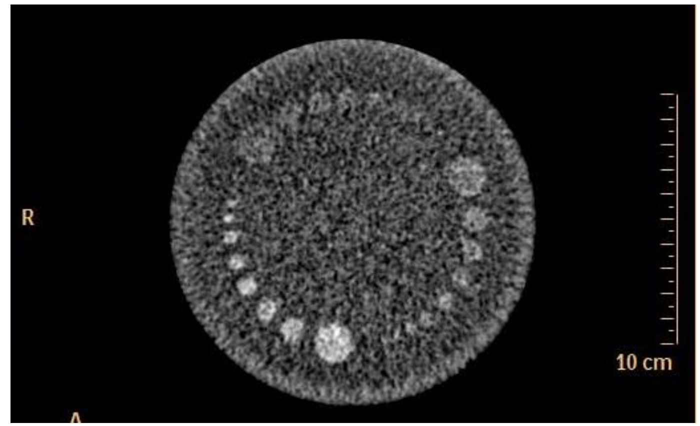
Same average noise reduction with NPS shift results in “PLASTIC” image.
iDose^4 preserves NPS and looks NATURAL

Low contrast specification at half dose
Spatial resolution specification at half dose

Low contrast resolution

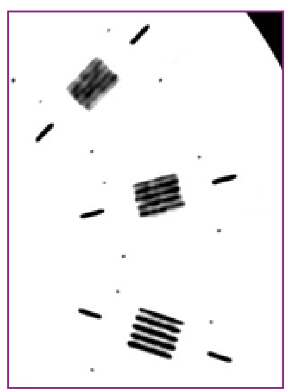


iDose, 4mm@0.3%, 13.5 mGy

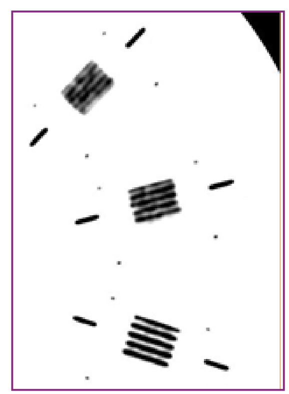


Current, 4mm@0.3%, 27 mGy

Spatial resolution



iDose 50% dose



Full dose

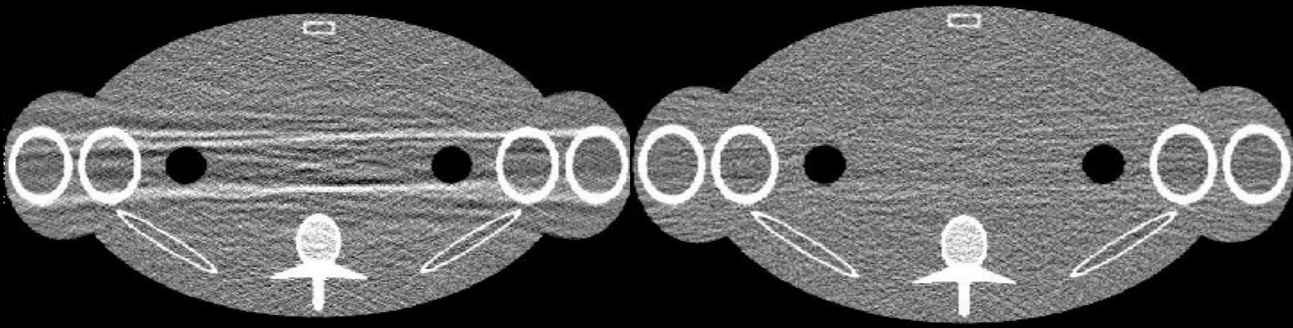
4^{th} Generation Reconstruction: iDose^4 Iterative Reconstruction Technique

	Key Clinical Benefits
Generation 4 Advanced Iterative Reconstruction	**Robust artifact prevention** **Improved Image Quality** **Preserves “natural” appearance**
Generation 3 Basic Iterative Reconstruction	**Artifact & noise reduction**
Generation 2 Image Based Filtering / Denoising	**Removal of some image noise**
Generation 1 Filtered Back-Projection (FBP)	**Fast**

Classification of reconstruction techniques based on the clinical results

iDose^4: Artifact Prevention

Through the optimal use of the projection data iDose^4 prevents artifacts.



Basic Iterative Reconstruction
Artifact *Reduction*

iDose^4
Artifact *Prevention*

More important than using the raw data is how well you use it !!!!
Generation 3 uses raw data and provides some amount of artifact reduction.

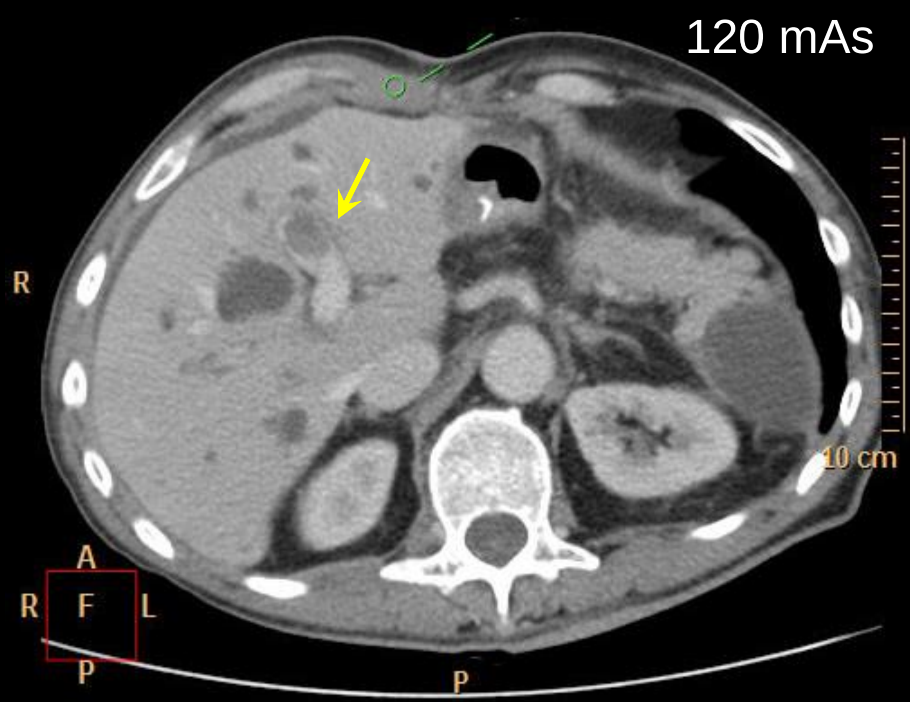
50% Dose Reduction for oncology follow up

120kV, 120 / 60 mAs

Apart from the cysts, the first CT shows thrombus in portal vein.
On the follow up study, (6 weeks later) the thrombus has disappeared.

Full Dose - FBP

120 mAs



50% Dose follow up + iDose

60 mAs

Courtesy Dr Dobritz, TU Munich, Germany

Image quality improvement for obese patient

↑ IQ = Dose

FBP iDose^4

Obese patient: 140kV, 30mAs, CTDI = 2.6 mGy

YB, Average 2.2 mm SW

Courtesy UMC Utrecht, Netherlands

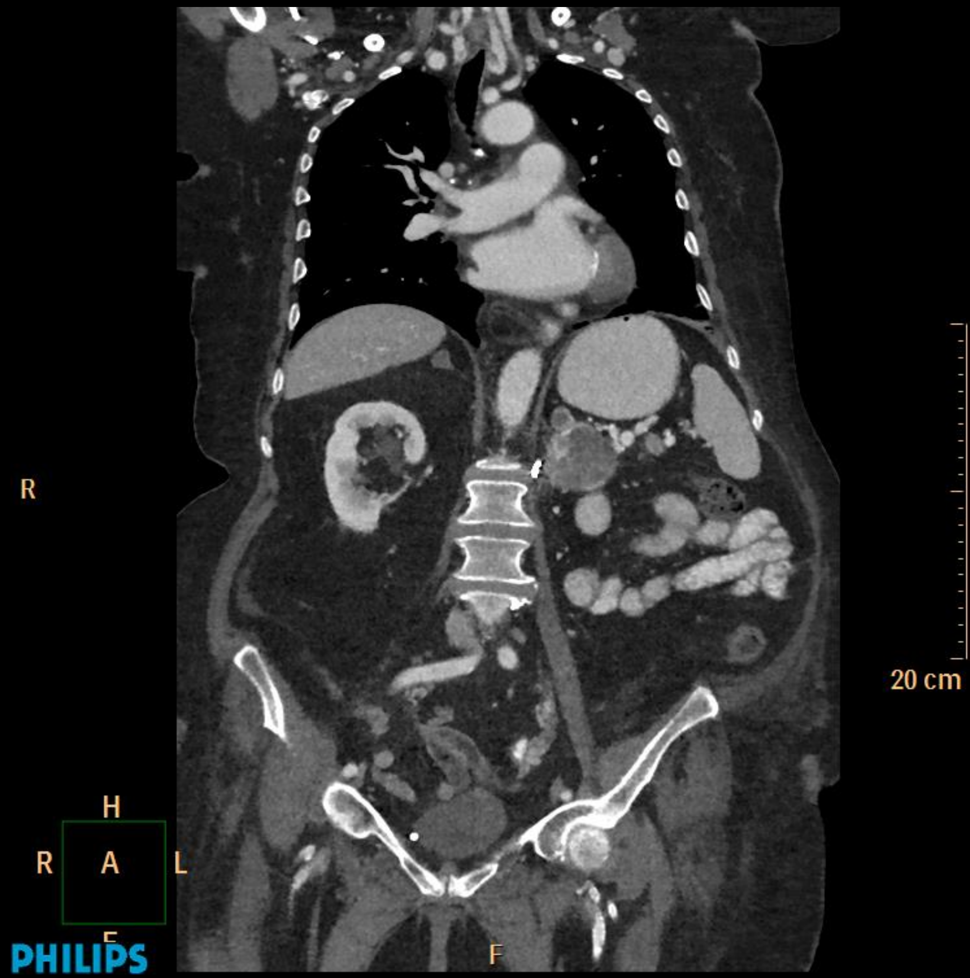
Improved visualization of soft tissue and structures

IQ Dose

Obese patient: 120 kV, 190 mAs: 10 mSv

FBP

iDose[4]

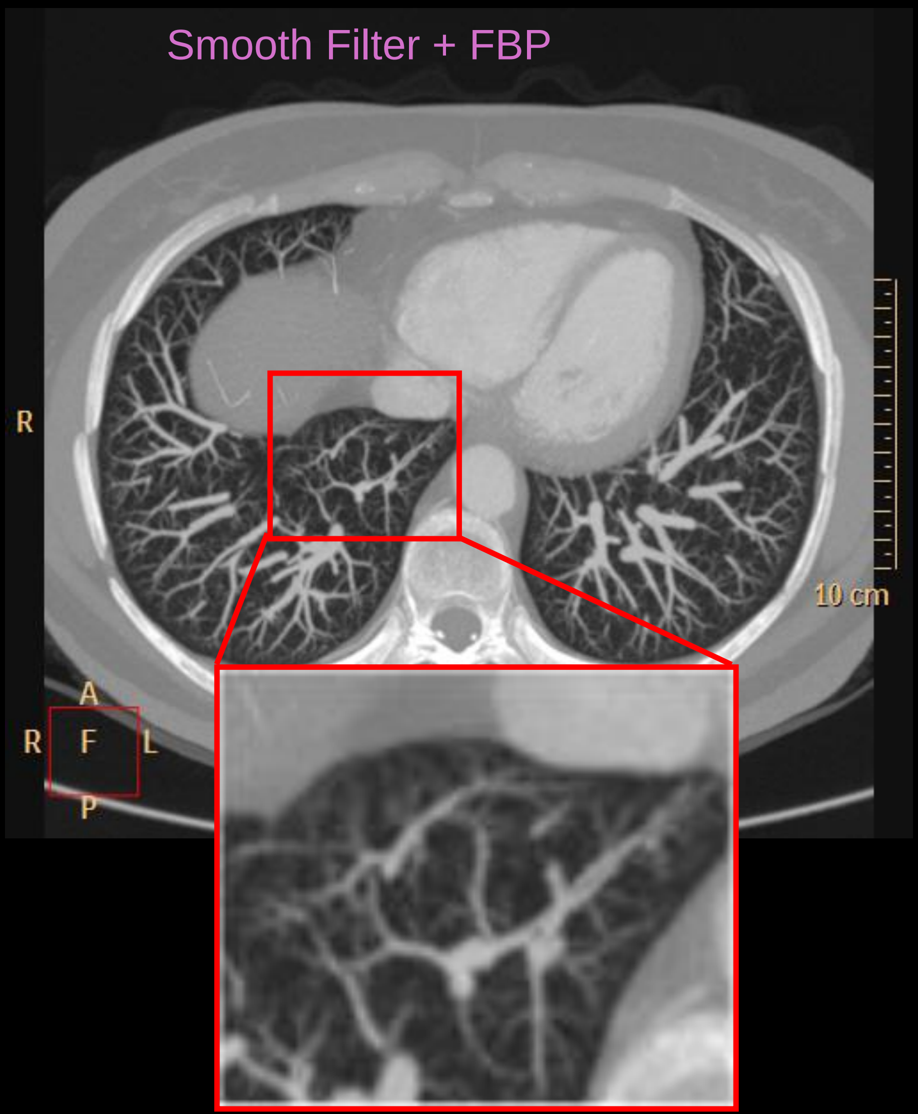


Courtesy TU Munich, Germany

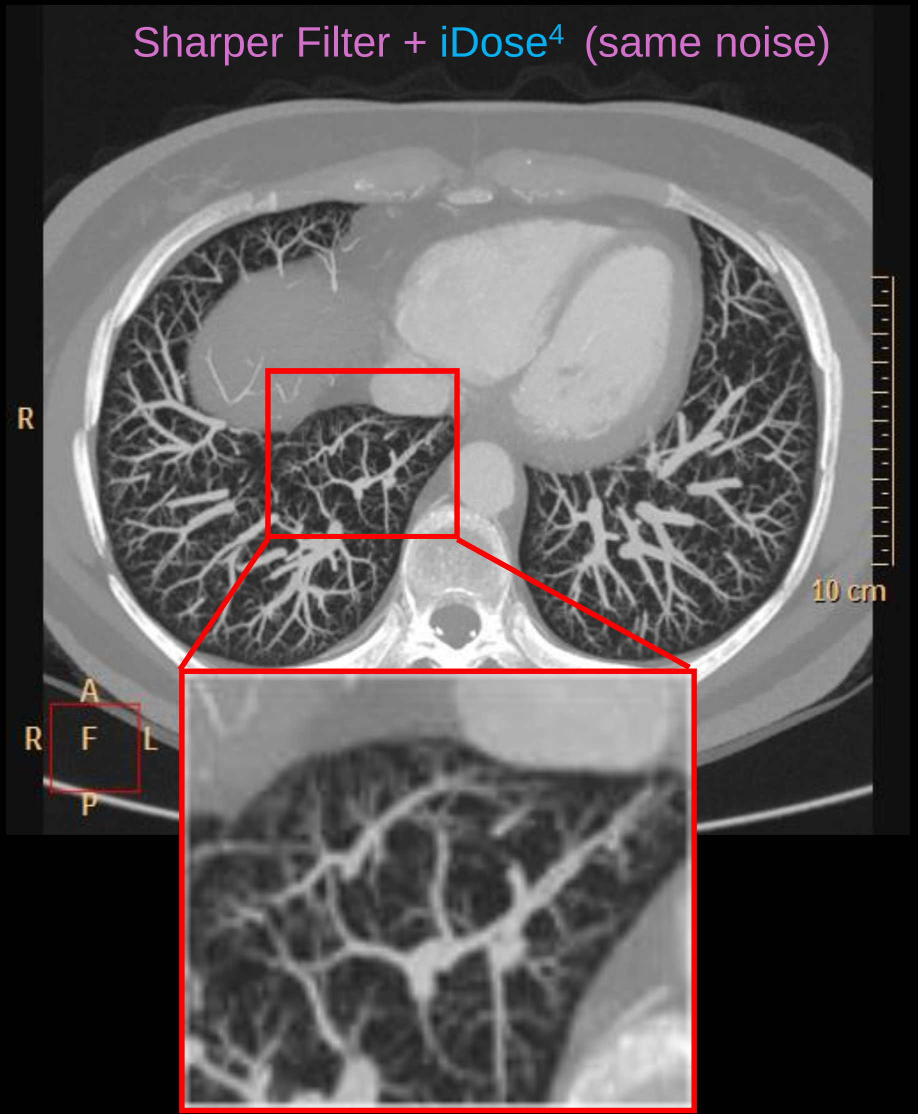
Up to 68% improvement in spatial resolution

IQ Dose

FBP

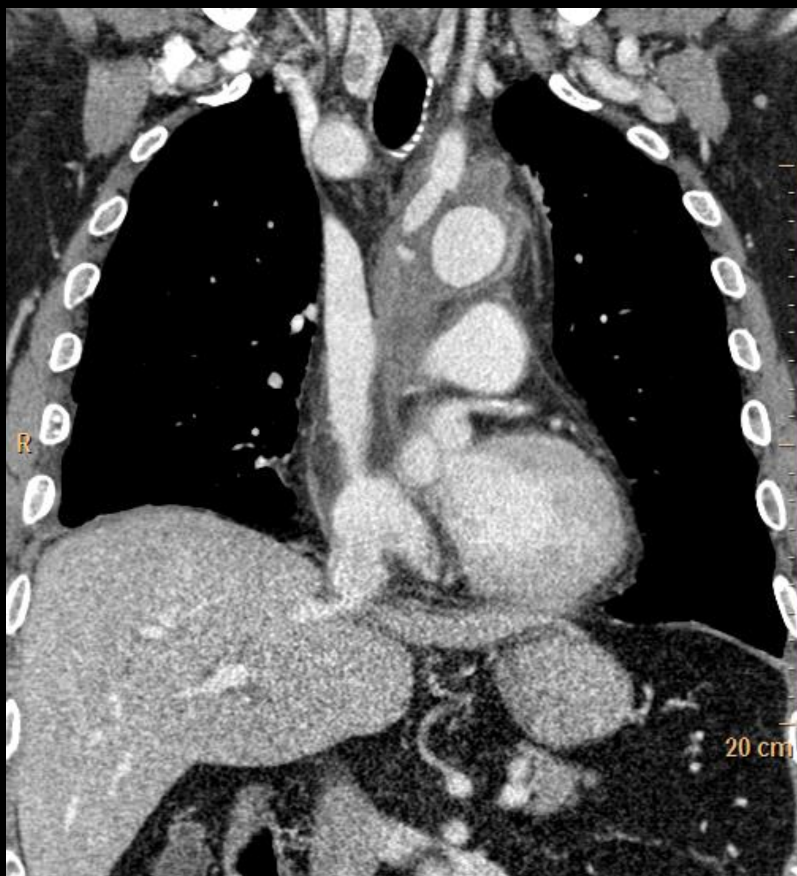


iDose^4

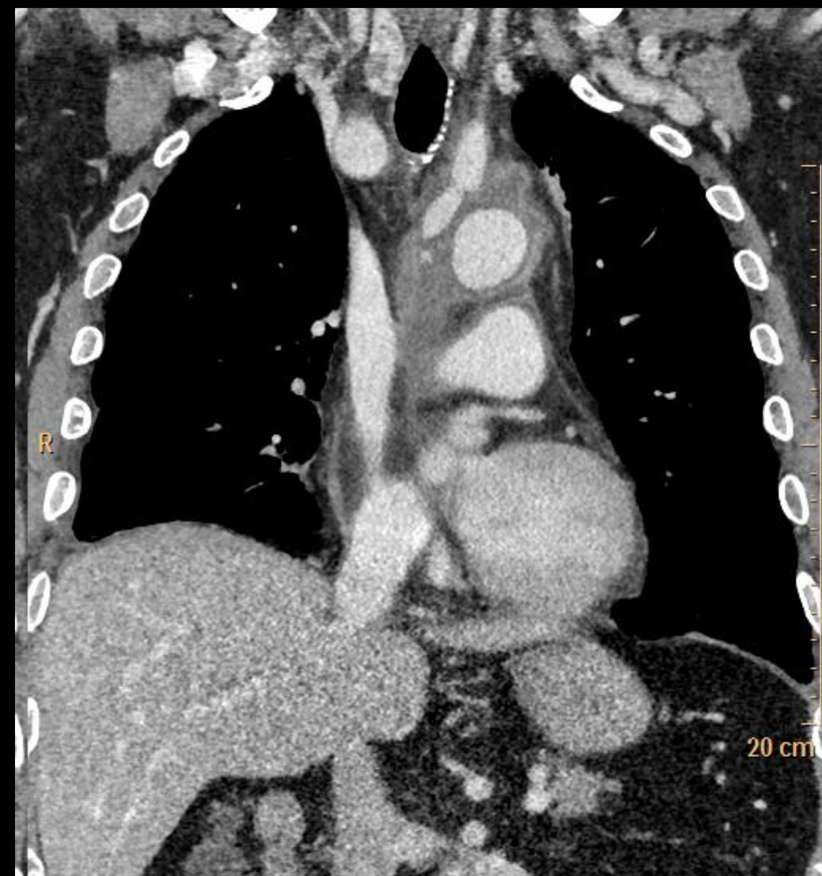


Courtesy UCL, Brussels, Belgium

iDose
50% less dose while maintaining diagnostic IQ



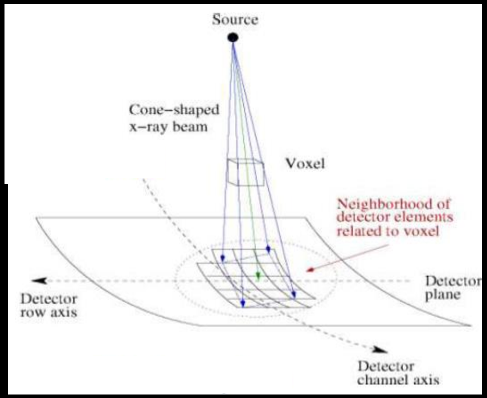
Original 7mSv Chest CTA



iDose 3.5mSv Chest CTA

Model Based Iterative reconstruction

Focal spot = real
Detector = real
Voxel = cube
X ray Beam = real
Statistical noise model
System model



Philips: IMR

GE: ASIR V

Canon: FIRST

Complex slow calculation
Low noise / dose
High Spatial AND Contrast Resolution

IMR

Knowledge-based Confidence

A New Era of CT Image Quality *and* Low Dose

Advanced scan modes

Diagnostic Confidence

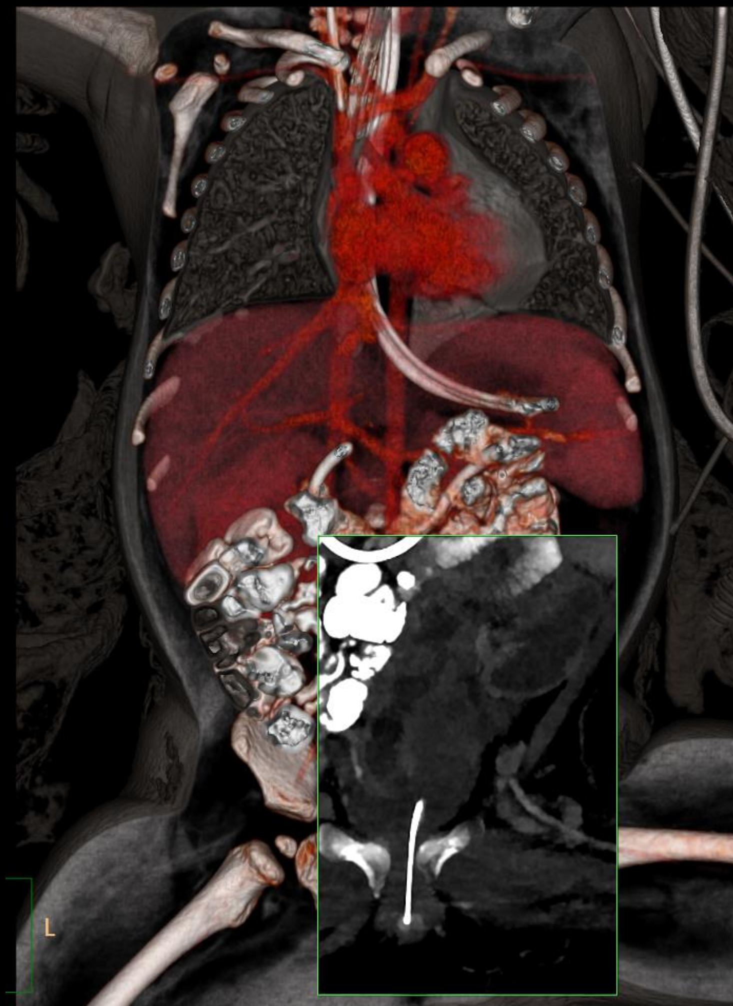
Subtle contrast differentiation

Increased clinical value with confidence

Anatomical detail

Lower Dose*

Fast



80 kVp, 70 mAs, 1.5 mGy, 51.5 mGy x cm, 3.0 mSv (k = 2 x 0.03*)
Courtesy: University of Maryland Medical Center, USA

** AAPM technical report 96*

** In clinical practice, the 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 a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task.*

IMR Knowledge-based Confidence

A New Era of CT Image Quality *and* Low Dose

Cardiac, perfusion, pulmonary gated

Up to 90% image noise reduction*

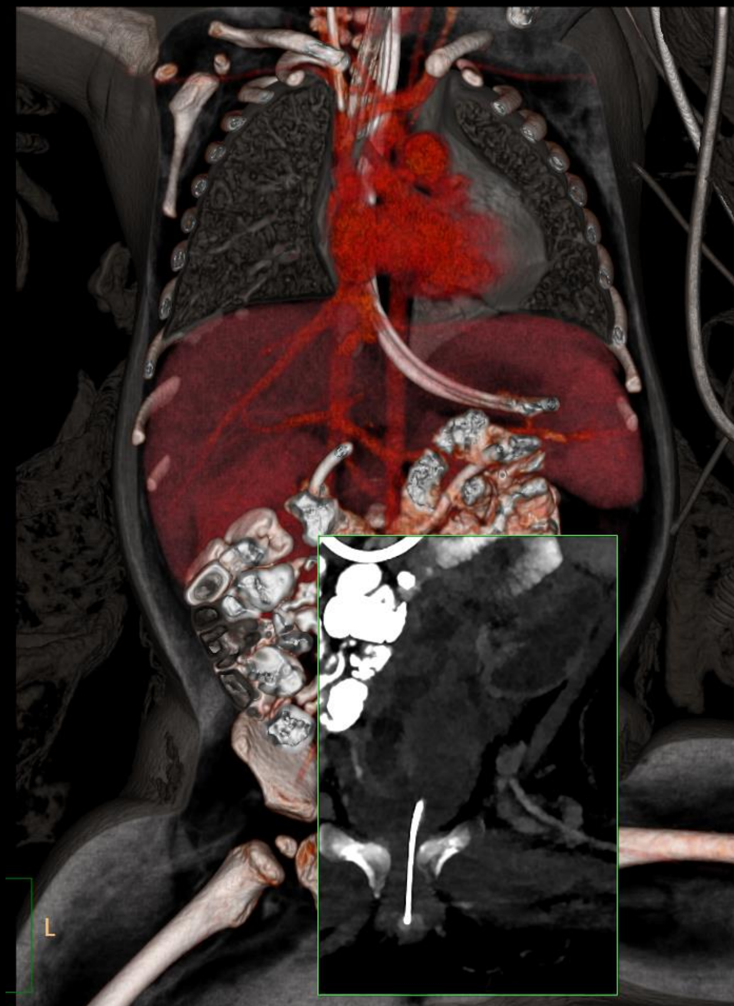
2.5x – 3.6x Low-contrast detectability*

Increased clinical value with confidence

1.2x – 1.7x Spatial resolution*

60 – 80% Lower dose *and* IQ improvement*

Majority of reference protocols < 3 min recon



80 kVp, 70 mAs, 1.5 mGy, 51.5 mGy x cm, 3.0 mSv (k = 2 x 0.03*)
Courtesy: University of Maryland Medical Center, USA
* AAPM technical report 96

** Lower image noise assessed using Reference Chest Protocol; Improved spatial resolution using Reference Abdomen and Thorax Protocols; Improved low-contrast detectability using Reference Abdomen Protocol; and dose reduction using Reference Abdomen Protocol. All metrics tested on phantoms. Dose reduction assessed on 0.8 mm slices, tested on the MITA CT IQ Phantom (CCT183, The Phantom Laboratory), using human observers.*

IMR Industry-leading

Low-contrast Resolution

3T MR

IMR

Lesion detected on CT, confirmed with MR on same patient

Courtesy: Amakusa Medical Center, Japan

IMR Low Dose *and* High Image Quality

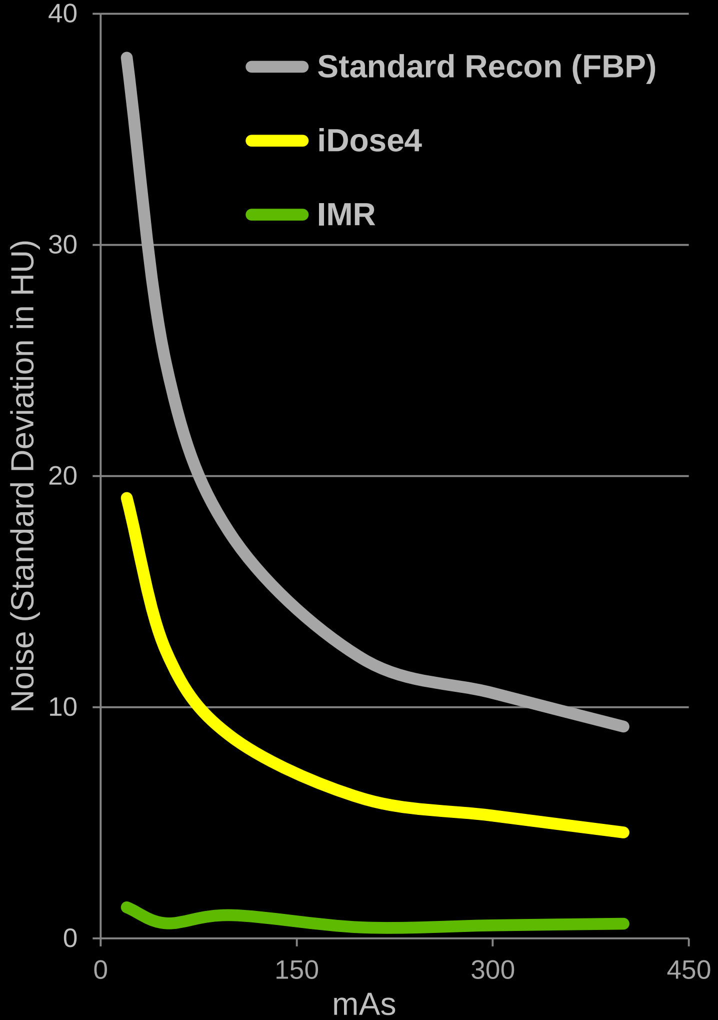
Simultaneously

60 - 80% Lower Dose + 43 - 80% Improved LCD + 70 - 83% Lower Noise

** In clinical practice, the 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 a physicist should be made to determine the appropriate dose to obtain diagnostic image quality for the particular clinical task. Low-contrast detectability and noise were assessed using Reference Factory Protocol comparing IMR to FBP; measured on 0.8 mm slices, tested on the MITA CT IQ Phantom (CCT183, The Phantom Laboratory), using human observers.*

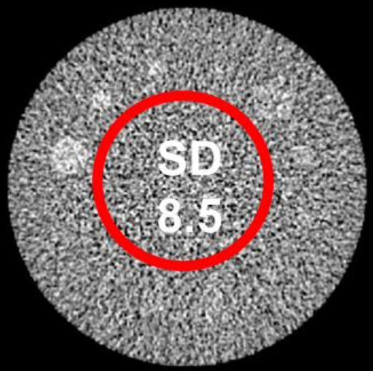
IMR Virtually Noise-Free Images

Revealing Critical Information



73 - 90%

Noise Reduction*



Standard Reconstruction

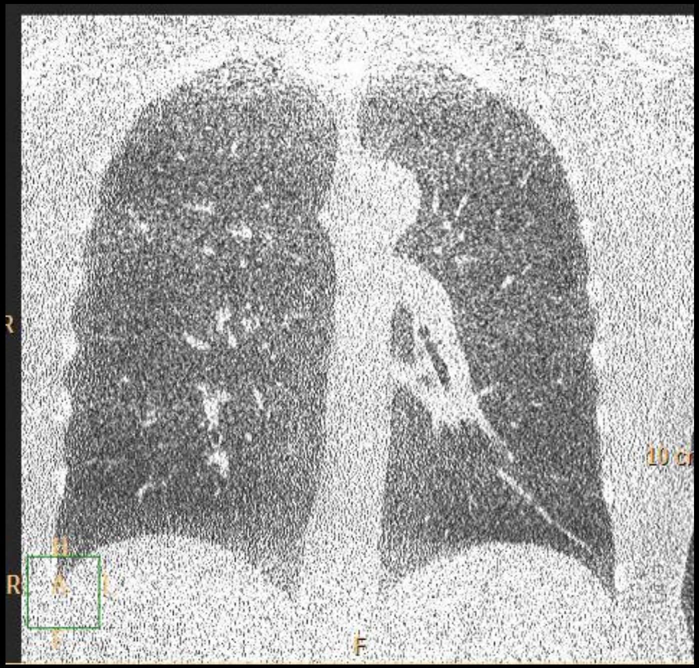
IMR

* *Image noise as defined by IEC standard 61223-3-5. Image noise was assessed using a Reference Chest Protocol, on a phantom. Data on file.*

Low Dose *and* High Image Quality

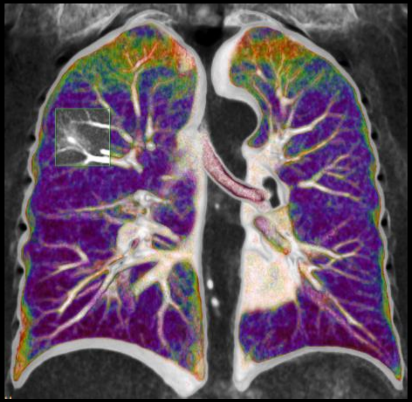
Simultaneously

GGO visualized on Chest CT with IMR

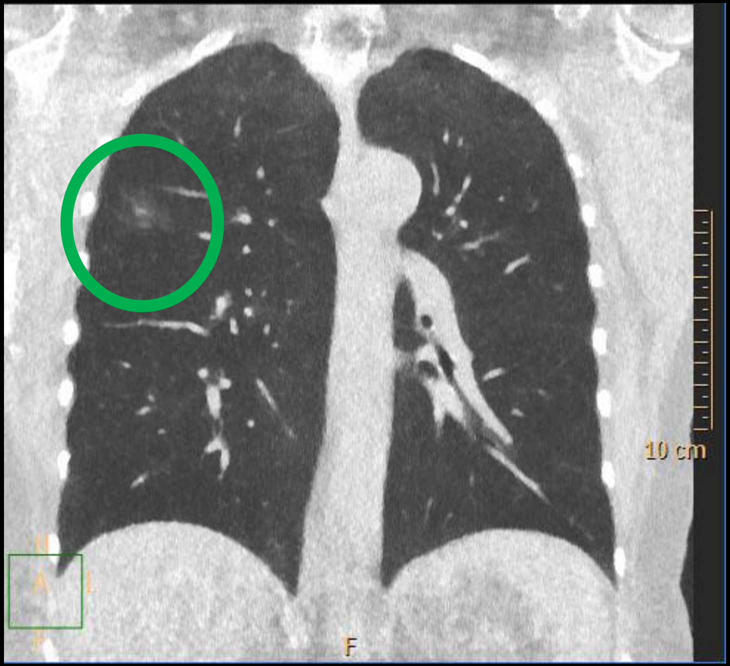


Standard Reconstruction
(FBP)

Chest X-Ray
0.05 mSv



Chest CT with IMR



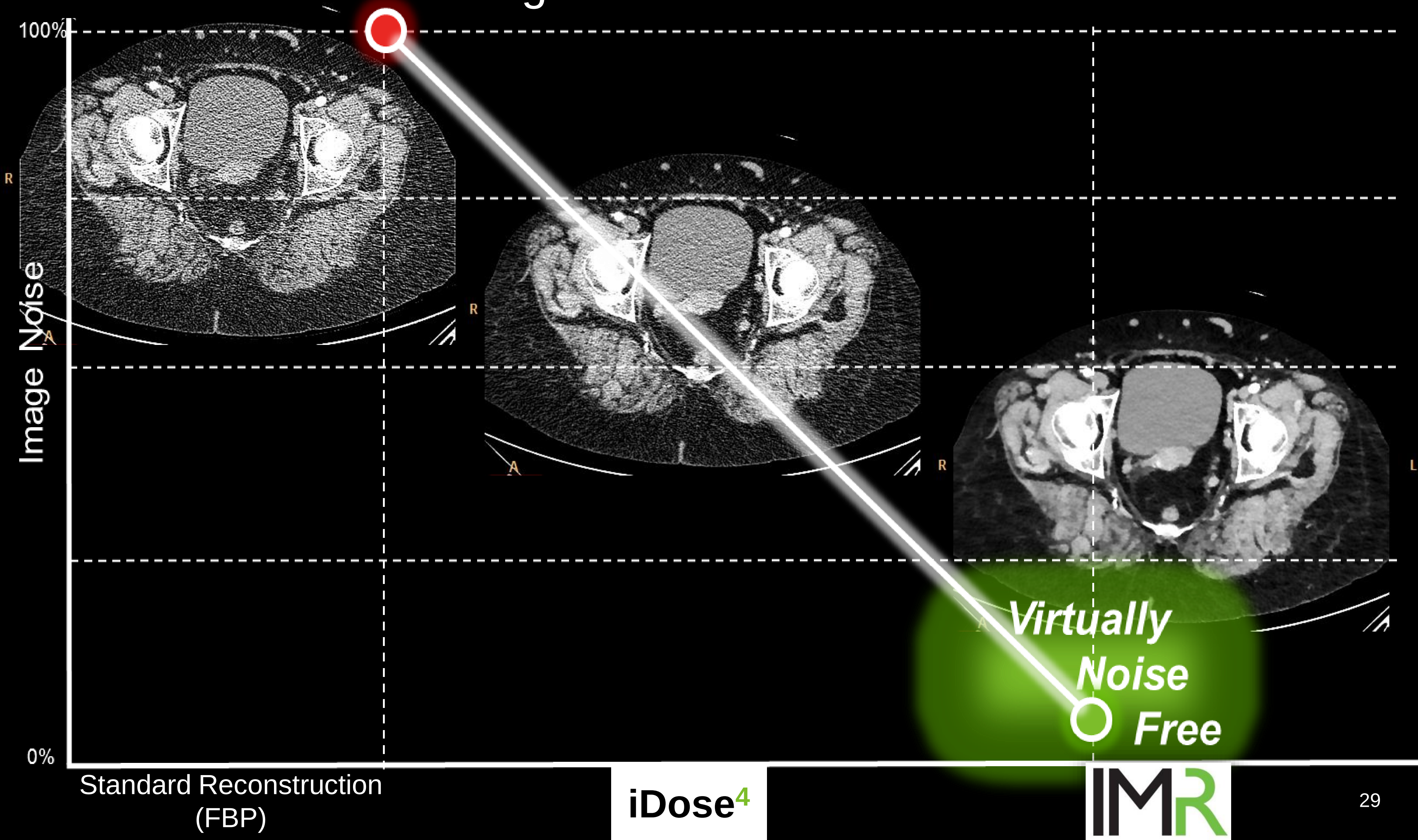
80 kVp, 10 mAs, 0.2 mGy, 8.2 mGy x cm, 0.11 mSv (k = 0.014*)

Courtesy: UCL, Belgium

* AAPM technical report 96

IMR Virtually Noise-Free Images

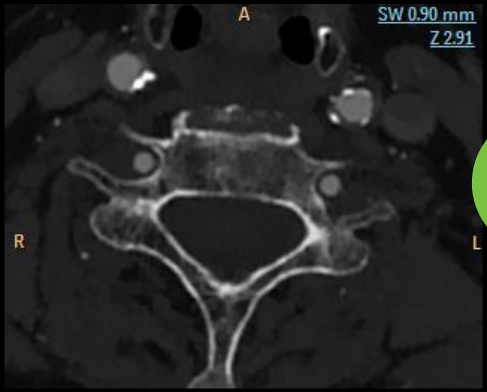
Revealing Critical Information



Improved resolution + better contrast + lower dose; within a single dataset

1.2x – 1.7x improved resolution*

Standard reconstruction



IMR

100 kVp, 200 mAs, 8.8 mGy, 35.1 mGy × cm, **0.7 mSv** (k=0.0021**)
Slice thickness 1 x 0.5 mm,

Exceptional contrast at low doses

"This is an exceptional iMR case as NCCT KUB was done at a radiation dose exposure (0.6mGy) equivalent to an x=ray KUB and yet produced images of exquisite details. A tiny 3mm calculus was seen in the right kidney on iMR images which was NOT seen on any other imaging modalities (US, X-ray), as well as images produced on a standard reconstruction. Hence low dose CT with iMR benefited this case to great extent"

Dr. Khandelwal & Team

PGIMER, India

kVP 80, mAs 50, Scan Length 38cm
CTDIvol 1mSv Dose 0.6mGy

PHILIPS

IMR Improve low-contrast detectability*

Detect Small and Subtle Differences

IMR

Standard Reconstruction
(FBP)

Courtesy: Guangdong General Hospital, China

** Low-contrast detectability was assessed using a Reference Abdomen Protocol, on the MITA IQ phantom, using human observers. Data on file.*

** AAPM technical report 96*

IMR Thin-slice Imaging Redefined

Low-Contrast *and* Low-Noise *and* High-Detail

71 year old man with hemorrhagic lesions not seen on FBP

1 mm slice thickness
Standard Reconstruction
(FBP)

3 mm slice thickness
Standard Reconstruction
(FBP)

1 mm slice thickness
IMR

120 kVp, 300 mAs, 14.3 mGy, 1.8 mSv (k=0.0021*)

Courtesy: UCL, Belgium

* AAPM technical report 96

Images Courtesy of:
Yeonsai UniversitySevrerence Hospital. Korea

iDose level3

IMR Routine level1

80 kVp,160 mAs, CTDIvol 6.4 mGy, DLP 306 mGy x cm, 0.9mSv (k=0.0031*)

IMR CAP

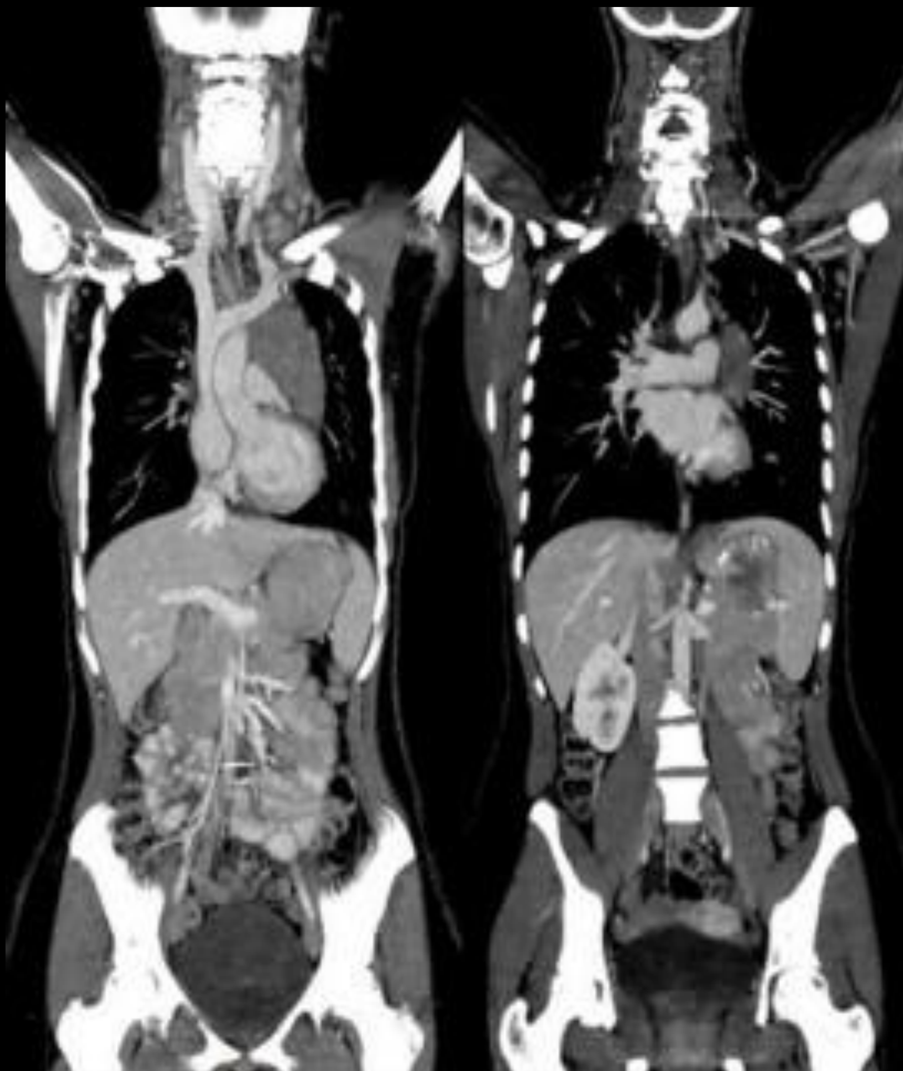


Image scan parameters
- 100 kVp
- 31 mAs/slice
- 2.6 mGy $CTDI_{vol}$
- 199 mGy x cm DLP
- 2.9 mSv effective dose (k=0.015)*

* AAPM Technical Report 96

(PHE reference 10 CTDI, 15 mSv)

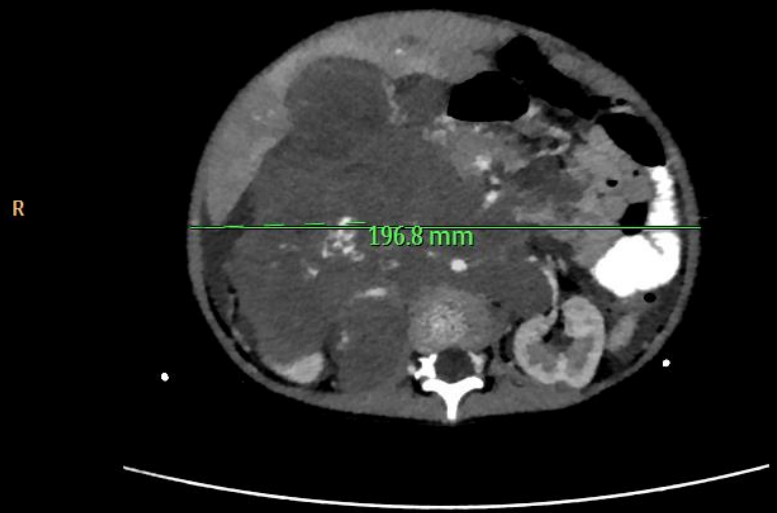
IMR CTPA

Parameters:
28 mL of contrast
Scanner: iCT
kVp: 100
mAs: 176
Dose: 3.9 mSv

Courtesy of:
Hokkaido University Hospital, Japan

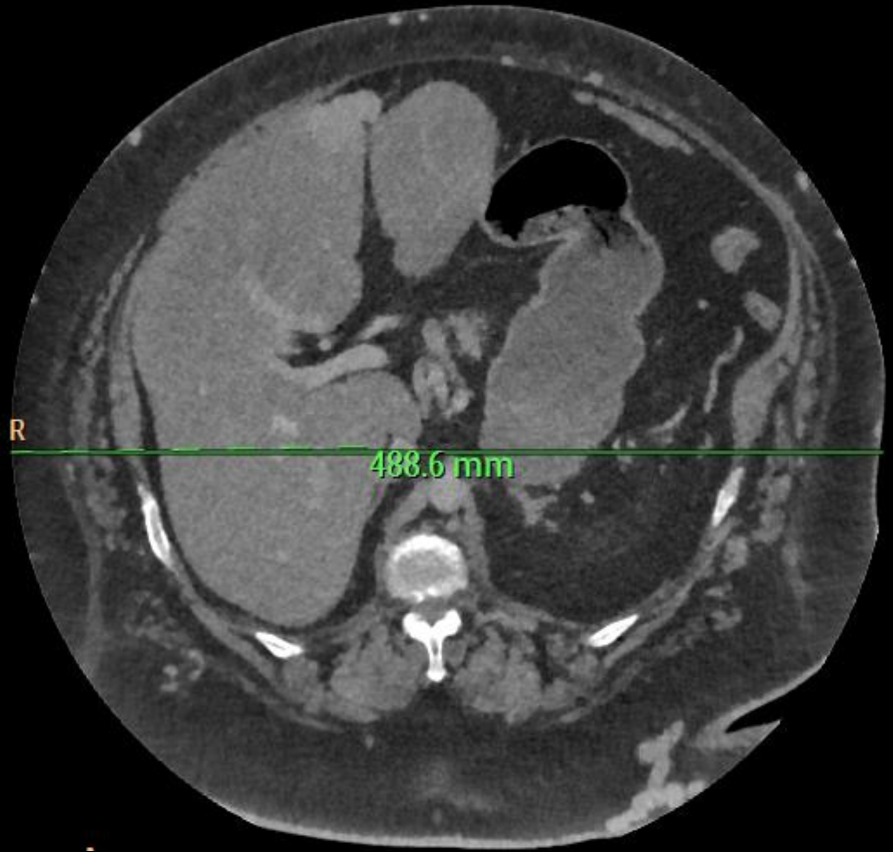
Consistency across patients

Virtually Noise-free for All Patients



1 mm slice thickness

Pediatric Patient



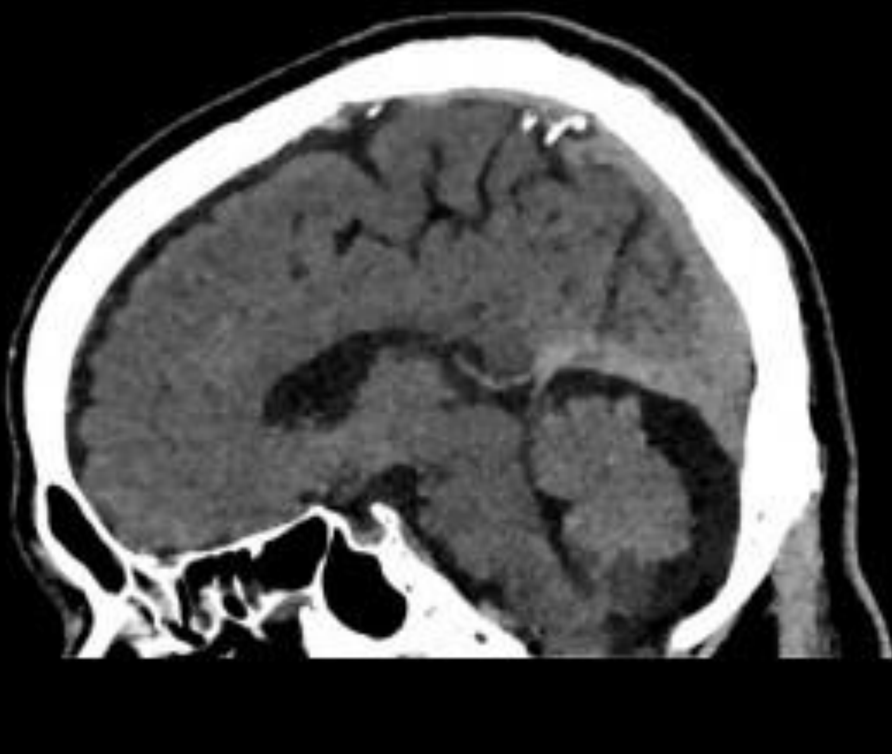
1 mm slice thickness

Bariatric Patient

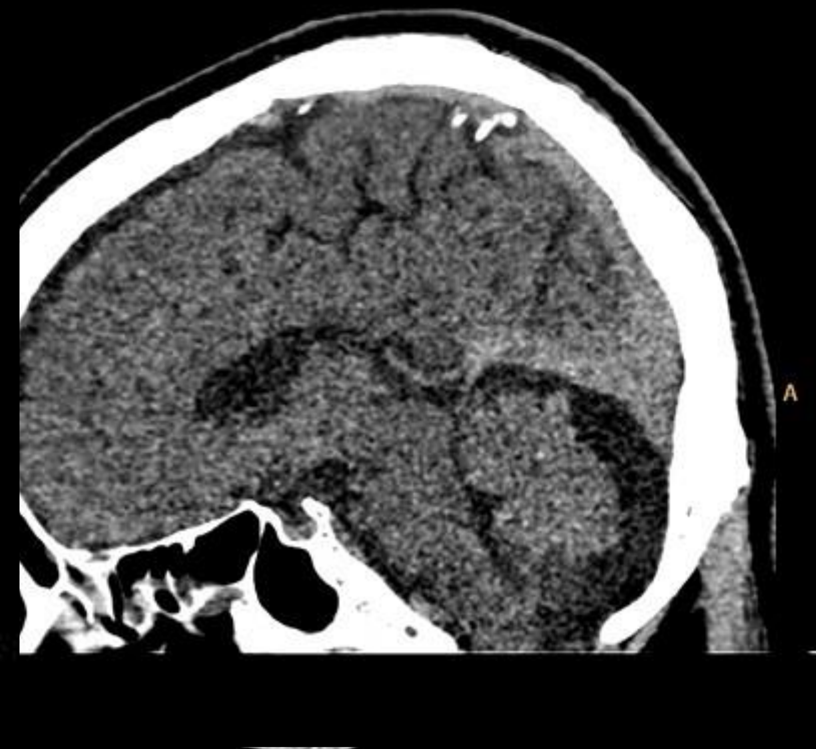
IMR In Routine Clinical Use

Dr Chee Yeong
Warrington & Halton Hospitals NHS FT

IMR Brain



IMR



iDose

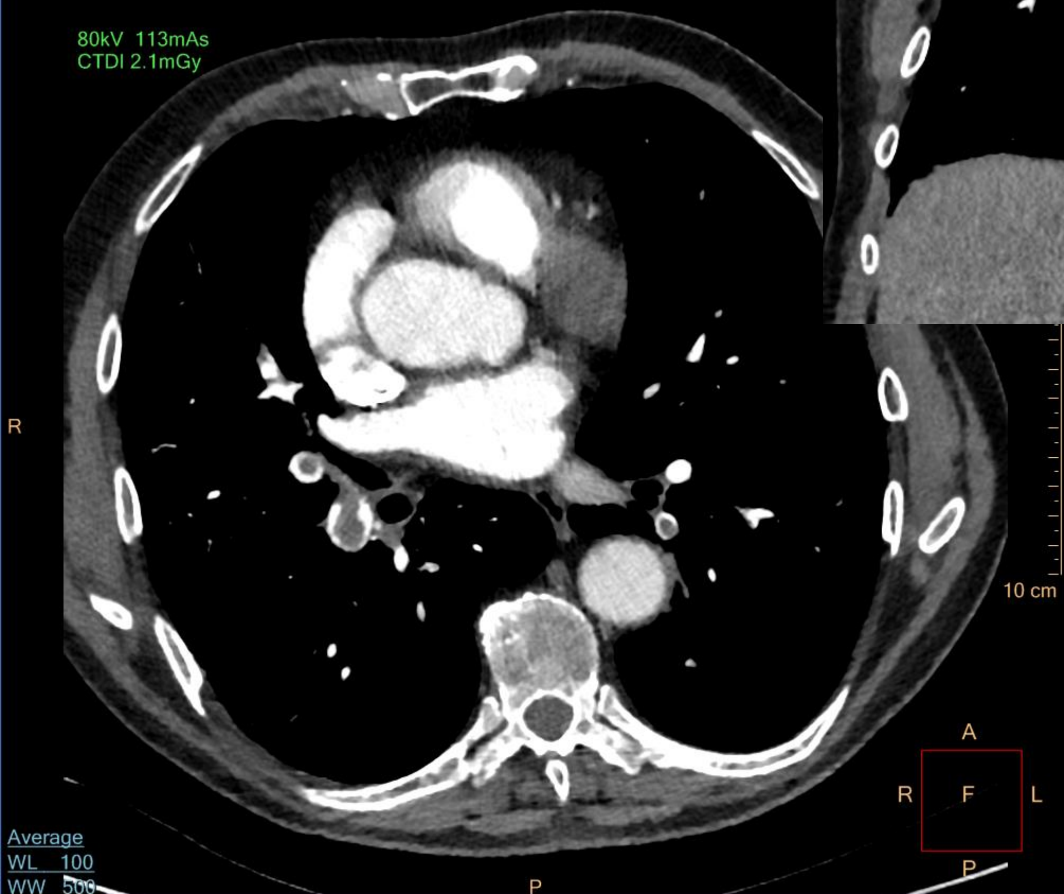
232 mAs

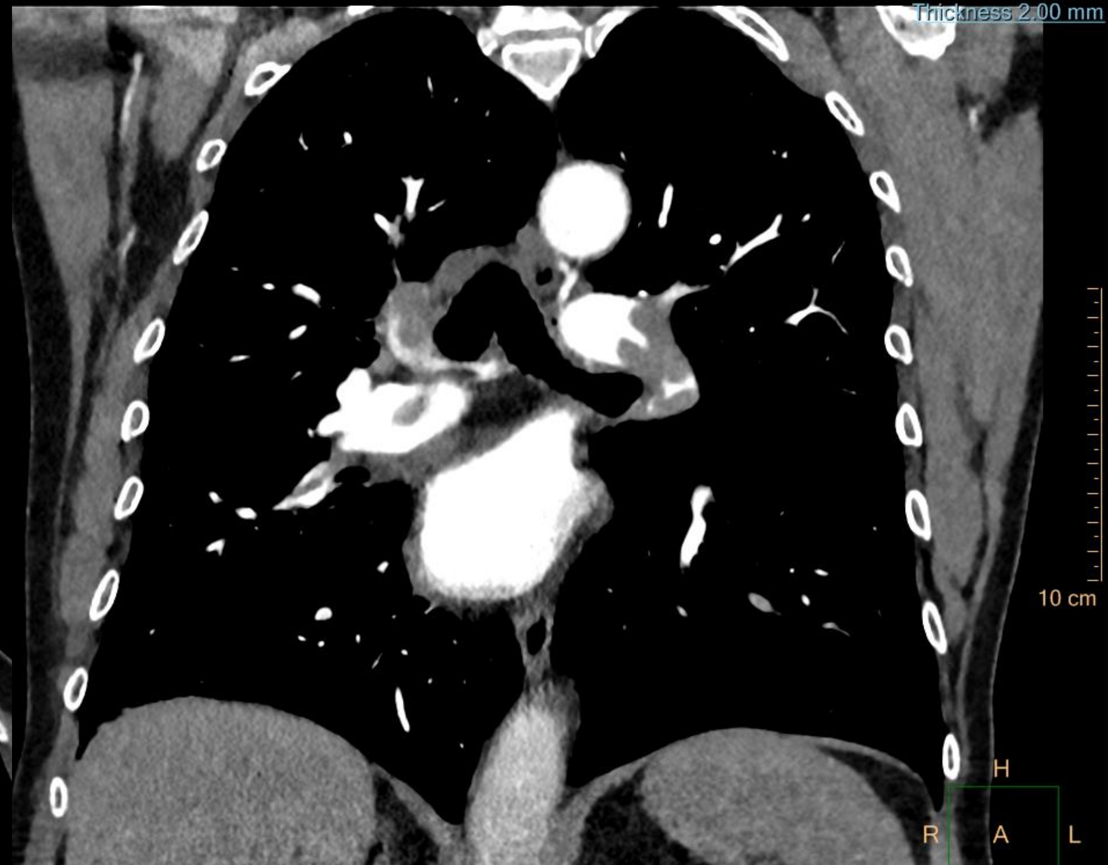
CTDI 30.1 DLP 488

(PHE reference: CTDI 58 DLP 890)

IMR CTPA

<85kg	80kV
85 – 120kg	100kV
>120kg	120kV





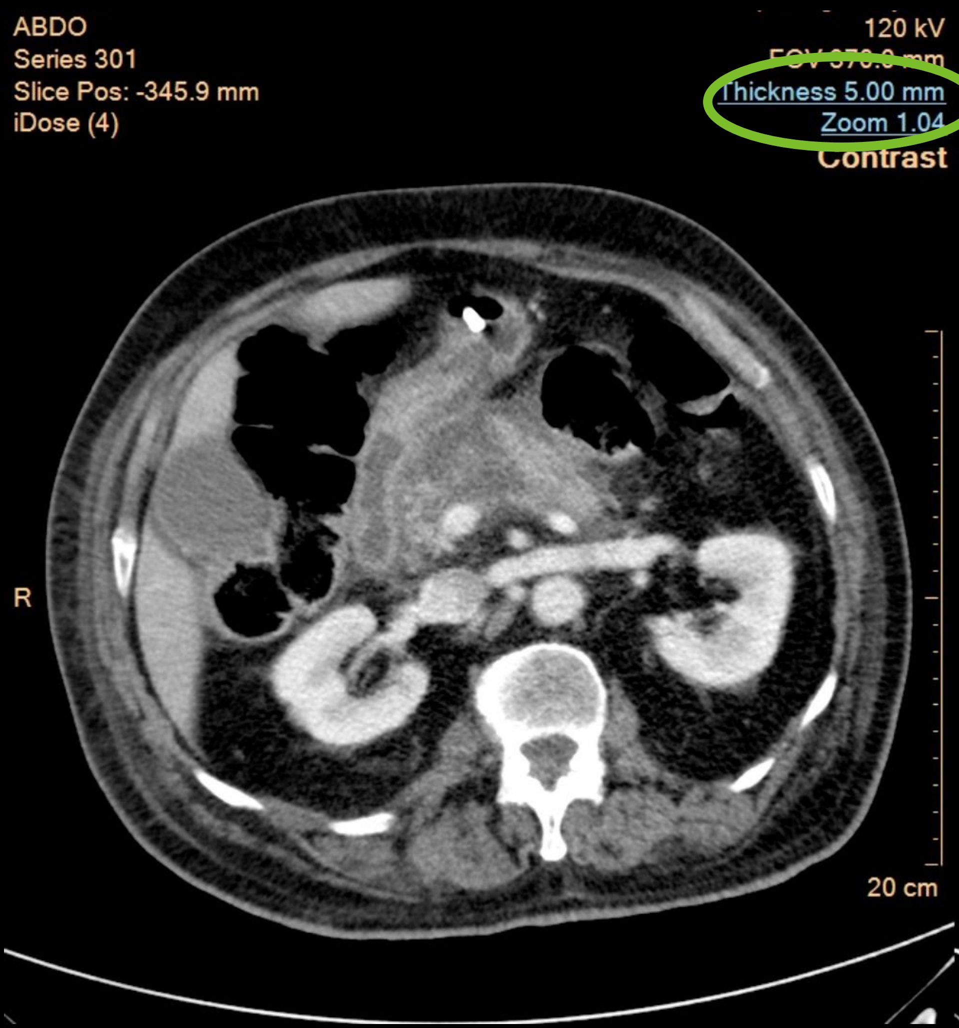
80 kV, 60mls of 300mg/ml contrast
80kg male
Ave **CTDI 2.6mGy**
DLP 95.5mGy*cm
1.3 mSv

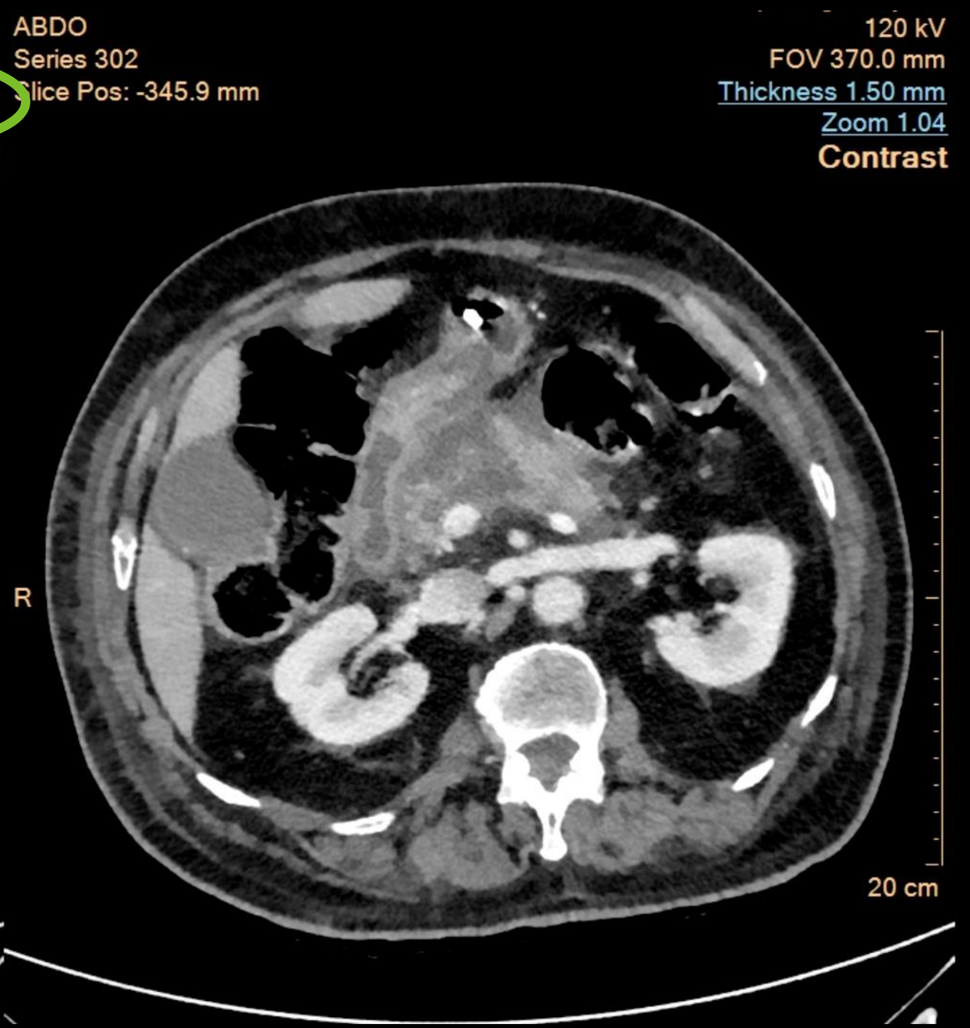
Reference:
Public Health England **CTDI 13 mGy**
8 mSv

IMR Very Low Noise

CTDI= 6mGy
120kV, 118mAs

Reference:
Public Health England **CTDI 13 mGy**

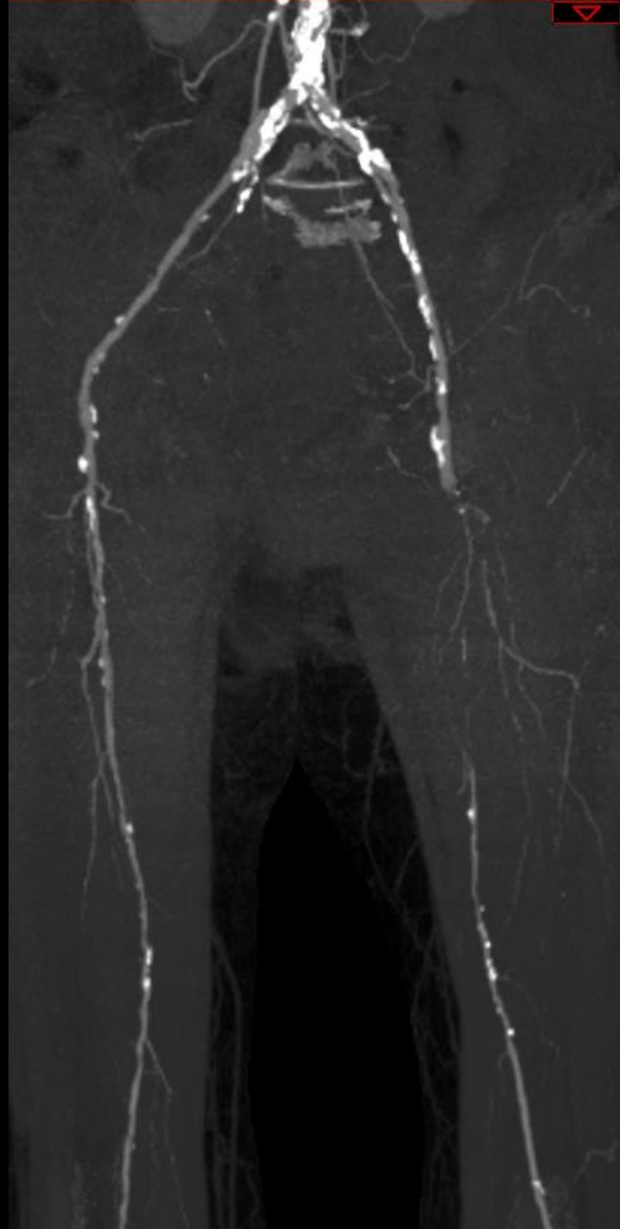




All scans 2 runs

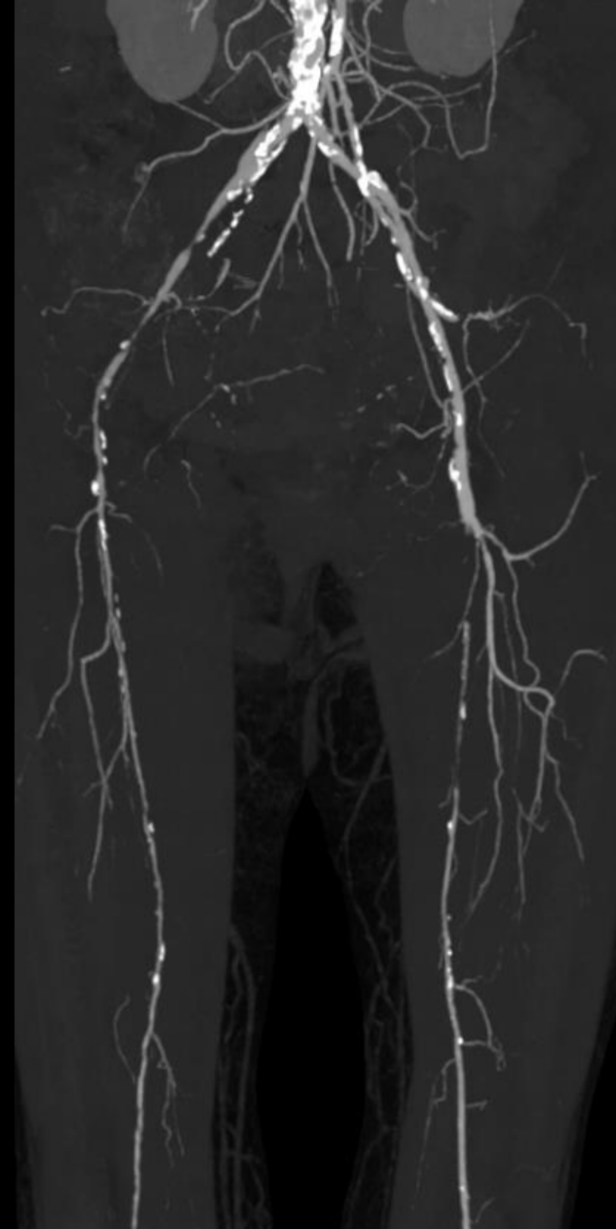
Total DLP: 1185 mGy*cm

FBP Vendor X



Total DLP: 2514mGy*cm

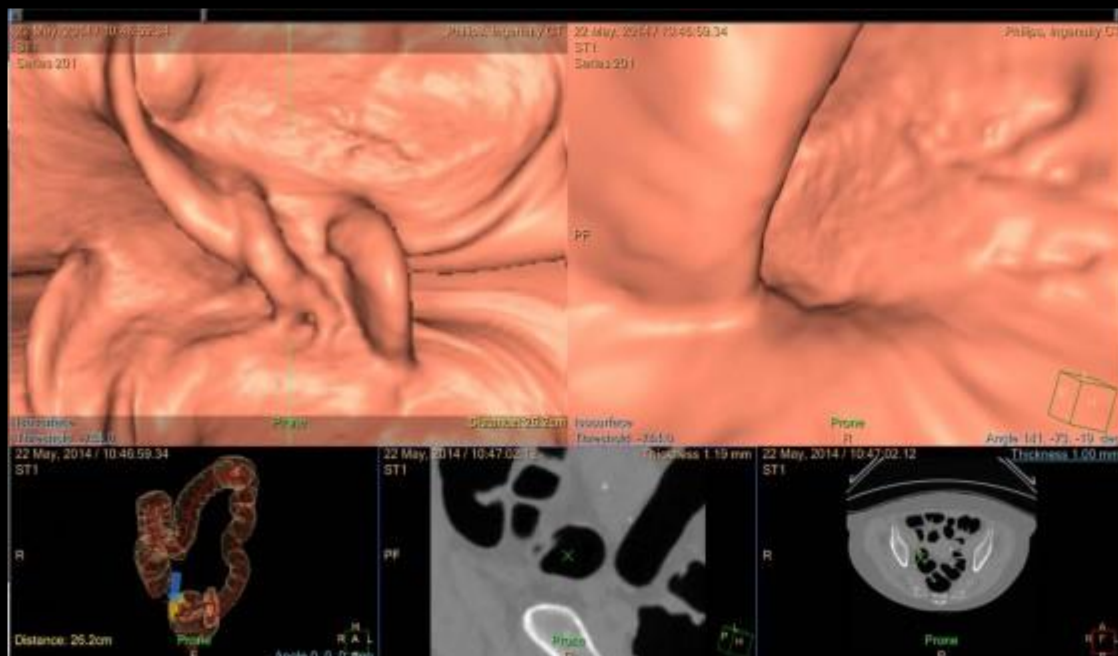
FBP Vendor Y



Total DLP: 284 mGy*cm

IMR

IMR CT Colonography



- Image scan parameters
- 120 kVp
- 10 mAs/slice
- 0.7 mGy $CTDI_{vol}$
- 29.2 mGy × cm DLP
- 0.6 mSv (k=0.015)* effective dose

PHE reference CTDI 11 (2 series)

IMR Cardiac CTA

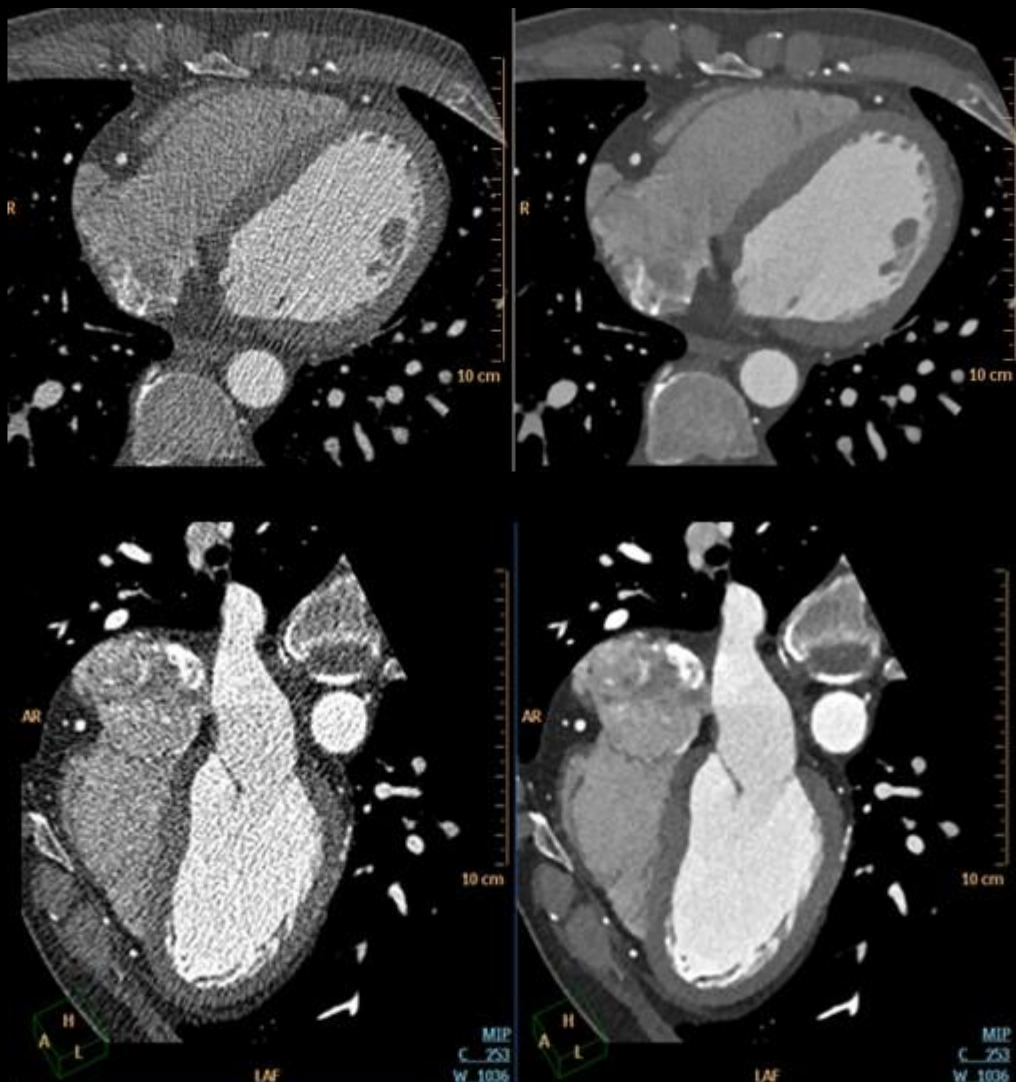


Image scan parameters

80 kVp

80 mAs

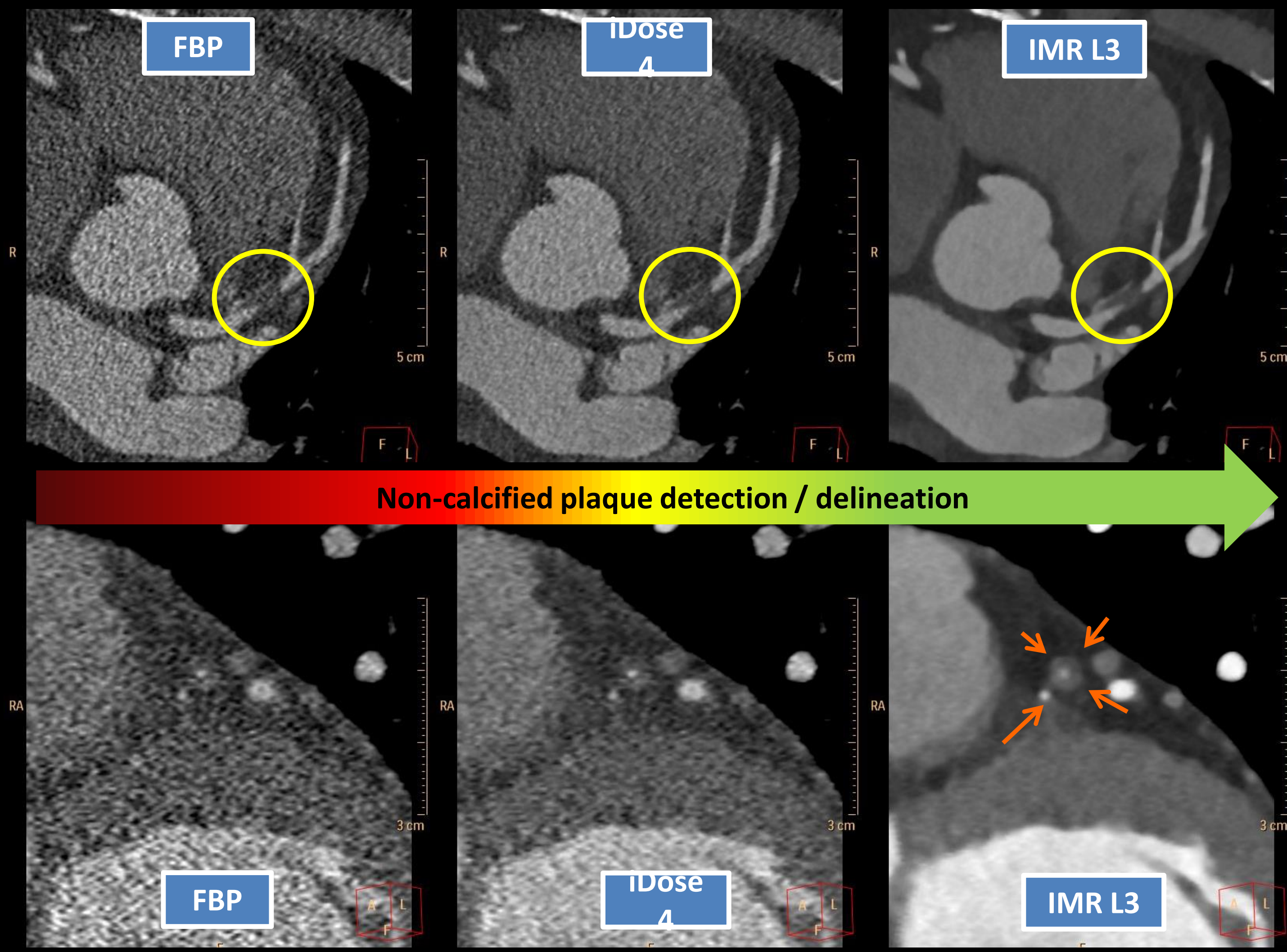
13.1 cm scan length

8.57 sec scan time

1.78 mGy $CTDI_{vol}$

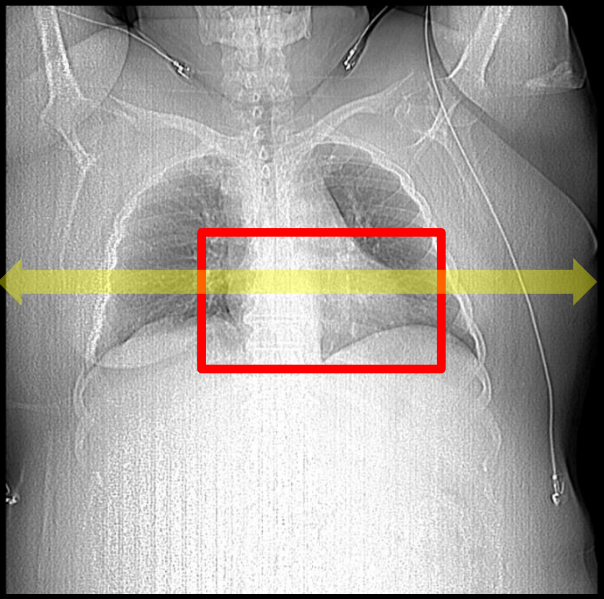
23.3 mGy × cm DLP

0.326 mSv (k=0.014)* effective

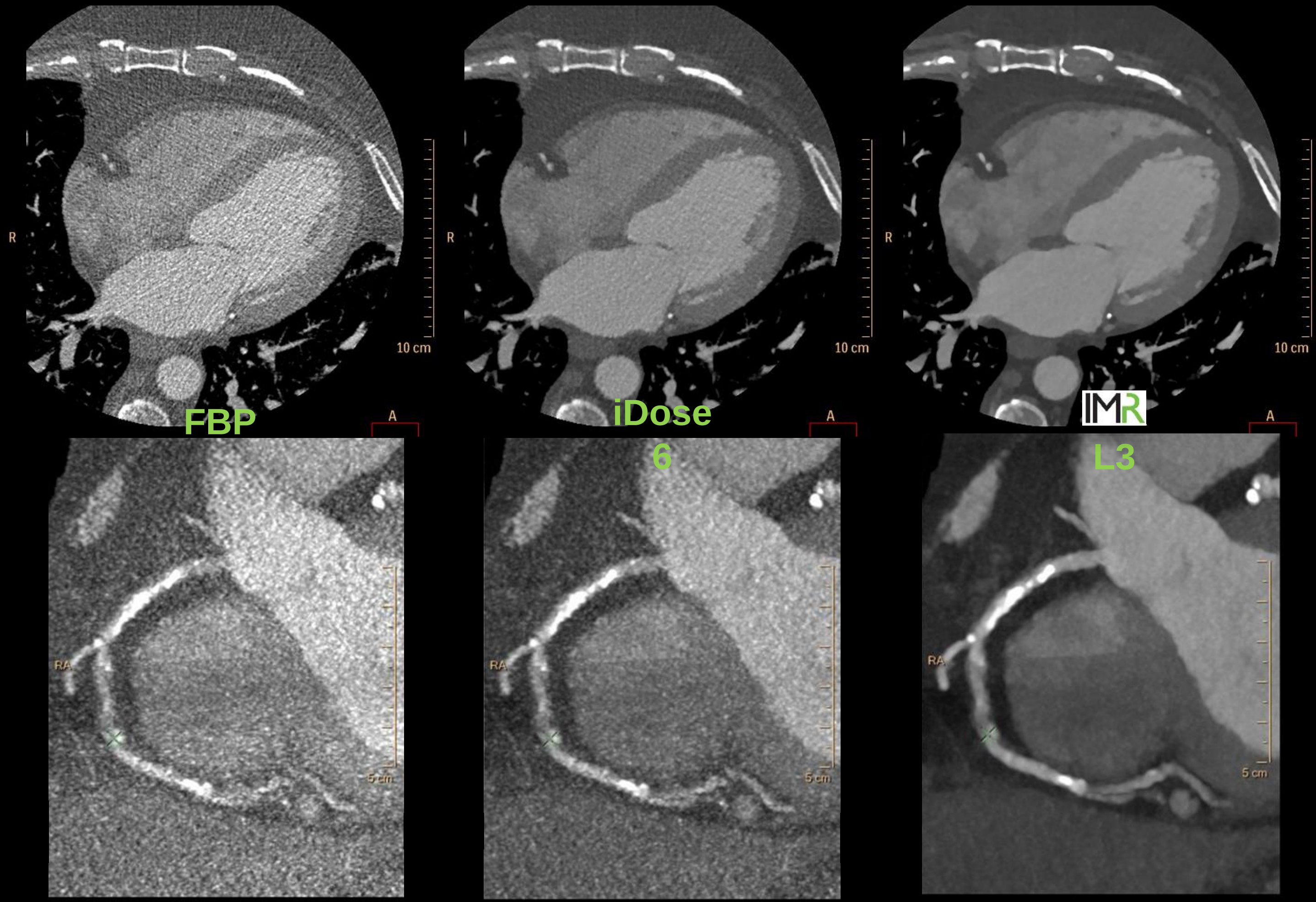

FBP
iDose 4
IMR L3
Non-calcified plaque detection / delineation
FBP
iDose 4
IMR L3

Images Courtesy of:
Semmelweis Univ. Budapest

Mixed plaque in
LM / LAD
in severe obese female
:
130kg, 170cm, **BMI 45**
Step&Shoot scan !
Max tube settings
120kV, 300mAs



Images Courtesy of:
Semmelweis Univ. Budapest



PHILIPS

Questions