

The Philips logo, consisting of the word "PHILIPS" in a bold, blue, sans-serif font, is positioned in the upper left corner of a white rounded rectangle. Below this rectangle is a green rounded rectangle containing the text "Computed tomography" in a white, sans-serif font.

Computed tomography

# Basic IMR testing, considerations and image quality trends

## Philips Iterative Model Reconstruction (IMR)

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Philips Iterative Model Reconstruction (IMR) has been developed to lower the image noise<sup>‡</sup> in CT images. IMR is a software application used to reconstruct images from a CT scanner with lower noise than can typically be attained with Filtered Back Projection (FBP). This feature can be used by radiologists as an alternative method to reconstruct CT raw data, instead of traditional FBP. The information in this paper describes the testing conducted in the development and testing of IMR, and how the results relate to the expected image quality performance.

### This paper is organized as follows:

- **Key performance metrics** – describes how the user can reconstruct and demonstrate, on their own, some of the key performance metrics of IMR
- **Basic testing** – allows the user to understand some key trends in how IMR reduces image noise, while maintaining or improving spatial resolution
- **Image quality trends** – identifies ways in which the noise behavior of IMR is different from that seen with FBP, allowing the user to better understand how clinical scans can be modified to take advantage of IMR's noise reduction capability
- **Special considerations** – Identifies special considerations in the way that IMR may make inherent image quality artifacts more apparent once the image noise has been reduced

<sup>‡</sup> Image noise as defined by IEC standard 61223-3-5. Image noise was assessed using reference body protocol, on a phantom. Data on file.

# Background

Different implementations of iterative reconstruction (image-based, statistical or hybrid-based, model-based, and knowledge-based) have been made commercially available by various vendors; there is continued debate in the scientific community with regard to the optimal implementation. Classification of reconstruction techniques based on their clinical results, as well as objective phantom-based measurements, provides a logical — and more meaningful — differentiation among these techniques. The classification in this paper is based on the value that reconstruction algorithms provide in terms of improving image quality, and reducing radiation dose.\*

Knowledge-based iterative reconstruction algorithms such as IMR differ from FBP methods in that the reconstruction becomes an optimization process that takes into account the data statistics, image statistics, and detailed CT system geometry. These optimization processes can be constrained by a cost function, which can give the user some control over the desired image characteristics.

Very simplistically, the cost function represents (a) the difference between an estimate of the data and the actual data that was acquired, and (b) a regularization term. Since it can be expected that a noisy image will be a valid solution to the reconstruction problem which minimizes the difference between estimate and actual data, a constraint (regularization) is required to get a better image. A constraint that penalizes image noise would drive the optimization process to produce noise-free images, and the level to which this is enforced can control the level of noise reduction. Such a constraint will take into account knowledge of the data statistic models. In other words, knowledge of the quantum noise statistics in the projection data could introduce bounds on the solution of the problem.

Also, in the formulation of the cost function there are known characteristics of the CT system that can additionally be used to target a desired resolution of the solution. For example, the achievable spatial resolution of the final image is driven by the detector sampling, angular sampling, and system geometries.

Spatial resolution can be maximized without the introduction of image artifacts by including this knowledge into the optimization process. Similar models for different system components and system physics can be introduced. Together, the careful consideration of the system properties allows for design of the cost function, enabling IMR to effectively control the image noise while maximizing spatial resolution at radiation doses that are significantly lower than those traditionally used with FBP reconstruction.\*

Philips IMR is a reconstruction technique that produces images containing lower levels of image noise compared to images produced by standard FBP reconstruction and advanced techniques, such as iDose<sup>4</sup>. The resulting IMR images can be used instead of conventional FBP images for diagnosis.

IMR is designed to reduce the dose\* required for diagnostic CT imaging. Image quality improvements and dose reduction\* depend 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 task. As with any imaging reconstruction, the quality of the resulting IMR images is dependent on scanning parameters, patient characteristics, and reconstruction choices.

In this paper, the evaluation of the impact of IMR noise reduction on image quality is assessed through the measurement of a set of image quality metrics on phantoms. These phantoms contain structures that allow for quantitative, reproducible measurements to be made in a controlled setting. The use of IMR as a means to improve various aspects of image quality and dose performance is assessed by comparing these image quality metrics with standard FBP reconstruction techniques and advanced techniques such as iDose<sup>4</sup>.

\* IMR is designed to reduce the dose required for diagnostic CT imaging. Image quality improvements and dose reduction depend on the clinical task, patient size, anatomical location, and clinical practice.

# Key performance metrics

The purpose of this section is to allow the user to not only understand the key image quality and dose performance capabilities of IMR, but also the objective evidence used to demonstrate those metrics. From this, the user can gain some expectation of, and confidence in, the performance capability of IMR.

Image quality testing using standardized methods [1] for objectively measuring noise, high-contrast spatial resolution, and low-contrast resolution was conducted on phantoms to provide reproducible objective data. The testing parameters were selected to provide de-noising effects expected to be appropriate for different clinical tasks. In general, these tests were repeated several times to achieve at least a 95% confidence level in reported results. Additional testing for evaluating the performance of IMR with respect to low-contrast detectability (LCD) was also conducted using a specialized low-contrast phantom, jointly designed by MITA and the FDA specifically to measure low-contrast detectability through observer studies with reconstruction parameters selected to provide high de-noising effects. The LCD was evaluated via an observer study. Descriptions of the image quality tests are provided later in this document. The acquisition and reconstruction techniques used to obtain this data for comparison are listed later in this document with the respective tests. The image quality metrics used are described in the Appendix at the end of this document.

## Performance metrics highlighted in this section

- IMR can reduce image noise by up to 90%, while maintaining or improving spatial resolution
- IMR can improve spatial resolution by at least 45% over FBP on the same acquisition, while improving or maintaining image noise
- IMR can simultaneously improve three image quality metrics – spatial resolution, image noise, and low-contrast resolution – compared to FBP on the same acquisition
- It is possible to reduce the dose\* by 80%, and use IMR to see an increase in spatial resolution by 20% while maintaining or improving image noise
- It is possible to reduce the dose\* by 60-80% and improve low-contrast resolution

\* IMR is designed to reduce the dose required for diagnostic CT imaging. Image quality improvements and dose reduction depend on the clinical task, patient size, anatomical location, and clinical practice.

# Ingenuity scanner

## Image noise reduction

The body and head sections of the Ingenuity system phantom (described in the instructions for use in the technical reference guide) are used for this test. The body section is used for the image noise (use the standard deviation [SD] of a Region of Interest [ROI] with area about 11,000 mm<sup>2</sup>), and the physics section of the head phantom is used to measure the modulation transfer function (MTF), which is the metric used for spatial resolution. With IMR, there is a significant reduction in image noise. When using a configuration like this, it is possible to measure up to a 90% image noise reduction (independent of artifact reduction) with an increase in MTF, with the following comparison.

### Thorax – Chest ExamCard

Parameter name	Parameter value
Tube potential	120 kVp
Tube charge per slice	306 mAs
CTDI <sub>vol</sub>	20 mGy
Scan mode	Helical
Rotation time	0.75 s

Parameter name	Parameter value FBP	Parameter value IMR
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	B	Soft tissue
Slice thickness	0.67 mm	0.67 mm
Slice increment	Overlap (0.335 mm)	Overlap (0.335 mm)
Matrix size	512 x 512	512 x 512

### Typical results seen for Ingenuity with system phantom

Scan #	Noise			50% MTF		
	FBP	IMR	% improvement	FBP	IMR	% improvement
1	49.3	2.9	-94.1%	2.997	3.869	+29.1%
2	49.8	2.9	-94.2%	3.397	3.825	+12.6%
3	49.0	2.9	-94.1%	3.211	3.791	+18.1%
4	49.5	2.8	-94.3%	3.077	3.727	+21.1%
5	49.2	2.8	-94.3%	3.803	3.799	-0.1%
<b>Average</b>			<b>-94.2%</b>			<b>+16.2%</b>

Note: the improvement in MTF shows a wide scatter, due to the variability of the FBP results. The IMR results are very consistent.

## Spatial resolution improvement

Traditional trade-offs between noise and spatial resolution in computed tomography exist via the reconstruction filter. In FBP, smoother filters can be used to produce images with less noise but with reduced spatial resolution. With IMR, noise is reduced while simultaneously improving high-contrast spatial resolution. The high-contrast MTF was measured using a standardized technique [2] on a Catphan® 600 phantom, module CTP591, using a 50 micron tungsten wire. For this test, image noise is measured as the SD of a smaller ROI in a uniform area, near the 50 micron wire. When using a configuration like this, it is possible to measure at least a 45% improvement in 50% MTF and a reduction of image noise with the following comparison.

### Abdomen – Abdomen ExamCard

Parameter name	Parameter value
Tube potential	120 kVp
Tube charge per slice	306 mAs
CTDI <sub>vol</sub>	20 mGy
Scan mode	Helical
Rotation time	0.75 s

Parameter name	Parameter value FBP	Parameter value IMR
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	A	Routine
Slice thickness	1.0 mm	1.0 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)
Matrix size	512 x 512	512 x 512

### Typical results seen for Ingenuity

Scan #	50% MTF			Noise		
	FBP	IMR	% increase	FBP	IMR	% decrease
1	2.939	4.876	+66%	5.4	2.3	-57%
2	2.937	4.744	+62%	5.1	2.5	-51%
3	3.092	4.883	+58%	5.3	2.5	-53%
4	3.054	4.903	+61%	4.6	2.2	-52%
5	2.983	4.447	+49%	5.4	2.4	-56%
<b>Average</b>			<b>+59%</b>			<b>-54%</b>

# Ingenuity scanner

## Simultaneous improvement of three image quality metrics

IMR can simultaneously improve spatial resolution, image noise and low-contrast resolution. One simple way to demonstrate this is to scan the entire Catphan® 600, and look individually at the CTP486 uniformity module, the CTP515 low-contrast module, and the CTP591 bead geometry and MTF wire module.

### Ingenuity – Abdomen ExamCard

Parameter name	Abdomen	
Collimation	64 x 0.625	
Pitch	0.80 ± 0.05	
Rotation time	0.5 s	
kVp	120	
mAs (CTDI <sub>vol</sub> )	306 (20 mGy)	
Parameter name	Parameter value FBP	Parameter value IMR
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	B	Routine
Slice thickness	0.90 mm	0.90 mm
Slice increment	Overlap (0.45 mm)	Overlap (0.45 mm)
Matrix size	512	512
Field of view	250 mm	250 mm

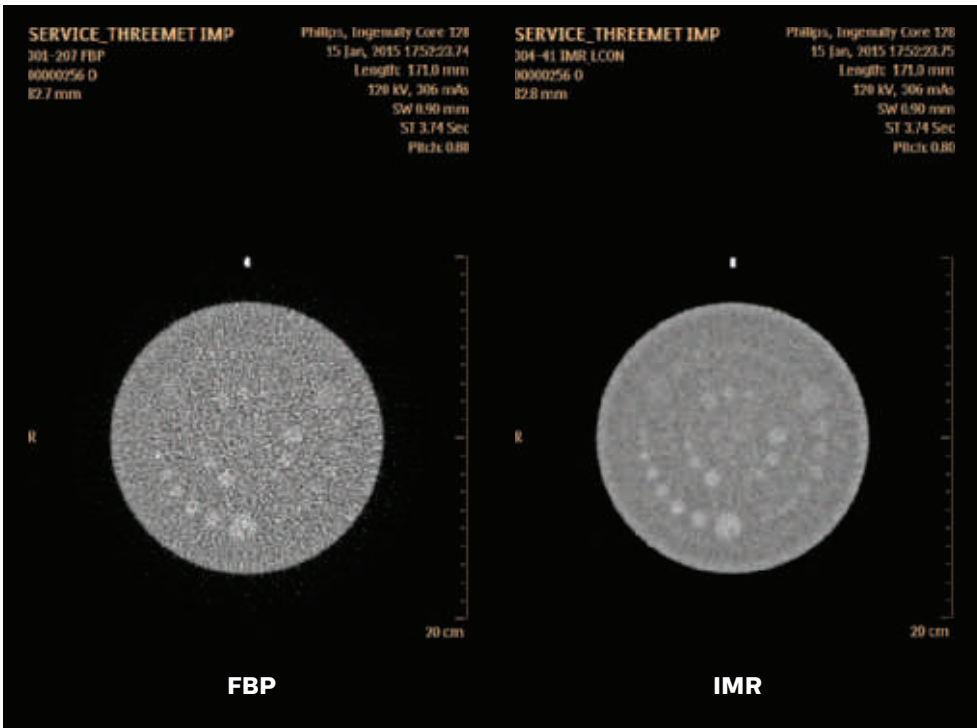
### Typical results seen for Ingenuity

Scan #	50 % MTF			10% MTF			Image noise		
	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?
1	2.975	3.889	Yes	5.340	6.551	Yes	9.9	2.6	Yes
2	2.755	3.740	Yes	5.275	6.670	Yes	9.9	2.6	Yes
3	2.751	3.773	Yes	5.344	6.714	Yes	10.0	2.6	Yes

Scan #	Number of 1% low-contrast pins visible			Number of 0.5% low-contrast pins visible			Number of 0.3% low-contrast pins visible		
	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?
1	6	8	Yes	2	6	Yes	0	4	Yes
2	7	8	Yes	4	6	Yes	0	4	Yes
3	7	8	Yes	3	7	Yes	0	5	Yes

- Using the wire in the bead and wire section, measure and record the 50% and 10% MTF for both reconstructions.
- Using the center of the uniformity section, and an ROI of about 5,000 mm<sup>2</sup>, measure the image noise in both reconstructions.
- Visually observe the low-contrast section, with Window Level 50, Window Width 80, and count the low-contrast pins distinguishable in each arc.

# Ingenuity scanner



**Figure 1** Low-contrast comparison between FBP and IMR with Ingenuity.

## Dose reduction\* and image quality

IMR is designed to reduce image noise in a CT image. IMR overcomes the typical trade-offs between noise and dose, and noise and spatial resolution. This allows a user to scan at lower doses\* without being impacted by increased image noise. Two different cases demonstrating that IMR allows the user to reduce dose\* and improve image quality at the same time are described in the following sections.

### Reduce dose\* and improve spatial resolution

The first case is that it is possible to reduce the dose\* and see an improvement in spatial resolution, while seeing lower image noise than with the FBP scan. When using a configuration like the following, it is possible to see a 20% improvement in 50% MTF with the following comparison.

### Ingenuity – Abdomen ExamCard

Parameter name	Parameter value FBP	Parameter value IMR
Collimation	64 x 0.625	64 x 0.625
Tube potential	120 kVp	120 kVp
Tube charge per slice	306 mAs	61 mAs
CTDI <sub>vol</sub>	20 mGy	4 mGy
Scan mode	Helical	Helical
Rotation time	0.75 s	0.75 s
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	A	Routine
Slice thickness	1.0 mm	1.0 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)
Matrix size	512 x 512	512 x 512

\* IMR is designed to reduce the dose required for diagnostic CT imaging. Image quality improvements and dose reduction depend on the clinical task, patient size, anatomical location, and clinical practice.

# Ingenuity scanner

## Typical results seen for Ingenuity

Scan #	MTF			Noise		
	FBP	IMR	% improvement	FBP	IMR	Ratio
1	2.939	4.501	+53%	5.4	3.6	-33%
2	2.937	4.604	+57%	5.1	3.7	-27%
3	3.092	4.458	+44%	5.3	3.9	-26%
4	3.054	4.206	+38%	4.6	3.9	-15%
5	2.983	4.352	+46%	5.4	3.9	-28%
<b>Average</b>			<b>+48%</b>	<b>-26%</b>		

Note: the improvements in MTF and noise show a wide scatter, due to the variability of the results. The spatial resolution improves by over 40%, while the image noise decreases, even though the CTDI is 80% lower for IMR\*.

## Reduce dose\* and improve low-contrast resolution

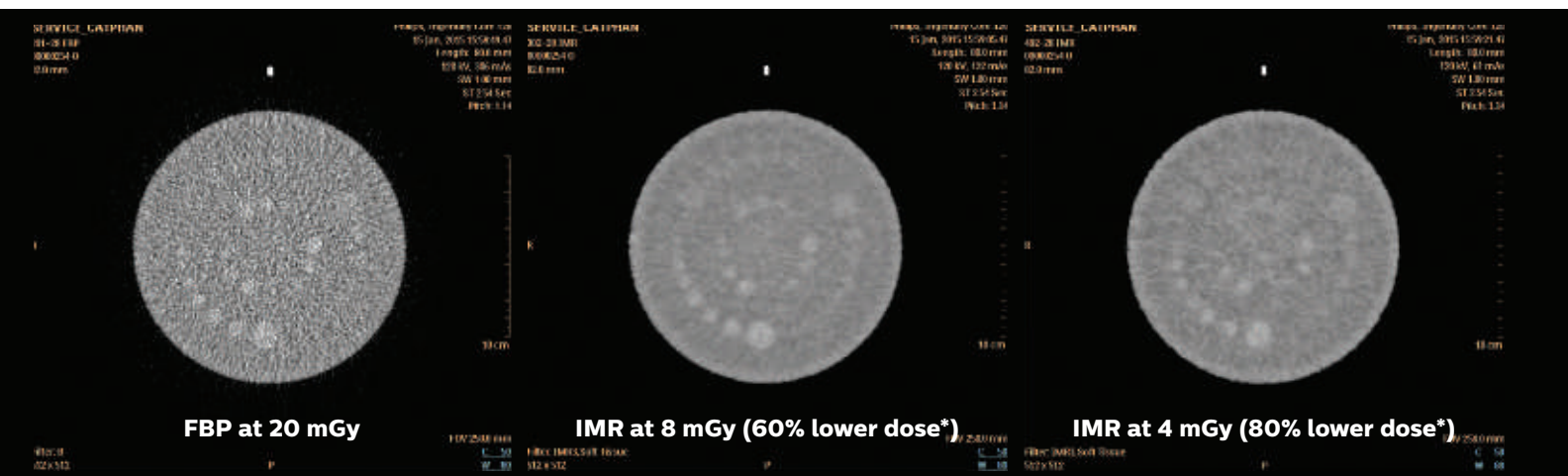
The second example of dose reduction\* considers low-contrast detectability. The Philips verification of this used a special image-quality phantom, developed by the MITA CT-IQ task force, and a detailed observer study. However, a special phantom is not needed to see that low-contrast detectability improves when using IMR and lower dose\*, and this is also seen with a standard Catphan.

Using a Catphan® 600 phantom, scan the CTP515 low-contrast module of the phantom using the scan parameters in the chart in the next column.

## Ingenuity – Abdomen ExamCard

Parameter name	Parameter value		
Collimation	64 x 0.625	64 x 0.625	64 x 0.625
Tube potential	120 kVp	120 kVp	120 kVp
Tube charge per slice	306 mAs	122 mAs	61 mAs
CTDI <sub>vol</sub>	20 mGy	8 mGy	4 mGy
Scan mode	Helical	Helical	Helical
Pitch	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.1
Rotation time	0.75 s	0.75 s	0.75 s
Reconstruction mode	Standard	IMR	IMR
Level	N/A	3	3
Filter/image definition	B	Soft tissue	Soft tissue
Slice thickness	1.0 mm	1.0 mm	1.0 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)	Overlap (0.5 mm)
Window center/width	50/80	50/80	50/80
Matrix size	512 x 512	512 x 512	512 x 512

After the reconstructions have finished, observe the central slice of the low-contrast module. You should see more low-contrast pins in the IMR reconstructions (at lower dose\*) than in the standard (FBP) reconstruction. Examples are shown in **Figure 2**. More pins are visible in either IMR image than in the FBP image.



**Figure 2** Dose reduction\* and image quality with Ingenuity.

\* IMR is designed to reduce the dose required for diagnostic CT imaging. Image quality improvements and dose reduction depend on the clinical task, patient size, anatomical location, and clinical practice.

# iCT scanner

## Image noise reduction

Image noise is measured by calculating the standard deviation (SD) of pixel values in a Region of Interest (ROI) of the uniformity section of the Catphan® 600 module CTP486. In addition, the Catphan 600 module CTP591 50 micron tungsten wire is used to measure modulation transfer function (MTF), which is the metric used for spatial resolution. To emulate typical adult body sizes, the Catphan CTP539 30 cm diameter annulus can also be used, but is not needed. With IMR, there is a significant reduction in image noise. When using a configuration like this, it is possible to measure up to a 90% image noise reduction (independent of artifact reduction) with an increase in MTF, with the following comparison.

### iCT – Thorax – Chest ExamCard

Parameter name	Parameter value
Tube potential	120 kVp
Tube charge per slice	273 mAs
CTDI <sub>vol</sub>	20 mGy
Scan mode	Helical
Rotation time	0.75 s

Parameter name	Parameter value FBP	Parameter value IMR
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	B	Soft tissue
Slice thickness	0.67 mm	0.67 mm
Slice increment	Overlap (0.335 mm)	Overlap (0.335 mm)
Matrix size	512 x 512	512 x 512

### Typical results seen for iCT with Catphan

Scan #	Noise			50% MTF		
	FBP	IMR	% improvement	FBP	IMR	% improvement
1	13.3	1.3	-90.2%	3.058	3.340	+9.2%
2	13.3	1.3	-90.2%	3.176	3.287	+3.5%
3	13.1	1.3	-90.1%	2.818	3.264	+15.8%
4	13.1	1.3	-90.1%	2.859	3.274	+14.5%
5	13.3	1.3	-90.2%	2.722	3.266	+20.0%
<b>Average</b>			<b>90.2%</b>			<b>+12.6%</b>

## Spatial resolution improvement

Traditional trade-offs between noise and spatial resolution in computed tomography exist via the reconstruction filter. In FBP, smoother filters can be used to produce images with less noise but with reduced spatial resolution. With IMR, noise is reduced while simultaneously improving high-contrast spatial resolution. The high-contrast MTF was measured using a standardized technique [2] on a Catphan 600 phantom module CTP591 using the 50 micron tungsten wire. For this test, image noise is measured as the SD of a smaller ROI in a uniform area, near the 50 micron wire. When using a configuration like this, it is possible to measure at least a 45% improvement in 50% MTF and a reduction of image noise with the following comparison.

### iCT – Abdomen – Abdomen ExamCard

Parameter name	Parameter value
Tube potential	120 kVp
Tube charge per slice	306 mAs
CTDI <sub>vol</sub>	20 mGy
Scan mode	Helical
Rotation time	0.75 s

Parameter name	Parameter value FBP	Parameter value IMR
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	A	Routine
Slice thickness	1.0 mm	1.0 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)
Matrix size	512 x 512	512 x 512

### Typical results seen for iCT

Scan #	50% MTF			Noise		
	FBP	IMR	% increase	FBP	IMR	% decrease
1	2.874	4.338	+46%	7.1	2.4	-66%
2	2.773	4.444	+67%	6.3	2.5	-60%
3	2.886	4.463	+58%	6.0	2.2	-63%
4	2.820	4.520	+70%	6.1	2.4	-61%
5	2.850	4.378	+53%	6.3	2.4	-62%
<b>Average</b>			<b>+59%</b>			<b>-62%</b>



# iCT scanner

## Simultaneous improvement of three image quality metrics

IMR can simultaneously improve spatial resolution, image noise, and low-contrast resolution. One simple way to demonstrate this is to scan the entire Catphan® 600, and look individually at the CTP486 uniformity module, the CTP515 low-contrast module, and the CTP591 bead geometry and MTF wire module.

### iCT – Abdomen ExamCard

Parameter name	Abdomen	
Collimation	128 x 0.625	
Pitch	0.90 ± 0.05	
Rotation time	0.4 s	
kVp	120	
mAs (CTDI <sub>vol</sub> )	296 (20 mGy)	
Parameter name	Parameter value FBP	Parameter value IMR
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	B	Routine
Slice thickness	0.90 mm	0.90 mm
Slice increment	Overlap (0.45 mm)	Overlap (0.45 mm)
Matrix size	512	512
Field of view	250 mm	250 mm

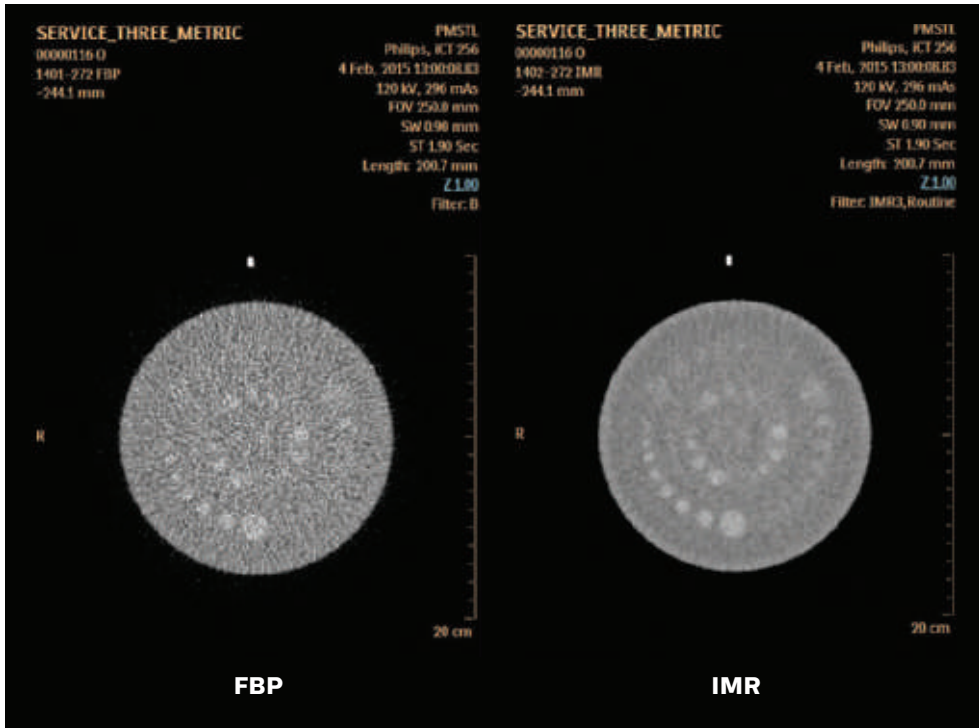
### Typical results seen for iCT

Scan #	50% MTF			10% MTF			Image noise		
	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?
1	2.762	3.528	Yes	4.973	6.009	Yes	9.7	2.6	Yes
2	2.723	3.841	Yes	4.866	6.860	Yes	9.6	2.6	Yes
3	2.786	3.434	Yes	4.911	5.899	Yes	9.6	2.6	Yes

Scan #	Number of 1% low-contrast pins visible			Number of 0.5% low-contrast pins visible			Number of 0.3% low-contrast pins visible		
	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?	FBP	IMR	Is IMR better?
1	5	8	Yes	1	5	Yes	0	2	Yes
2	5	8	Yes	2	3	Yes	0	3	Yes
3	7	9	Yes	1	4	Yes	0	3	Yes

- Using the wire in the bead and wire section, use the resolution test to measure and record the 50% and 10% MTF for both reconstructions.
- Using the center of the uniformity section and an ROI of 5,000 mm<sup>2</sup>, measure the image noise in both reconstructions.
- Visually observe the low-contrast section, with Window Level 50, Window Width 80, and count the low-contrast pins distinguishable in each arc.

# iCT scanner



**Figure 3** Low-contrast comparison between FBP and IMR with iCT.

## Dose reduction\* and image quality

IMR is designed to reduce image noise in a CT image. IMR overcomes the typical trade-offs between noise and dose, and noise and spatial resolution. This allows a user to scan at lower doses\* without being impacted by increased image noise. There are two key examples where IMR allows the user to reduce dose\* and improve image quality at the same time.

### Reduce dose\* and improve spatial resolution

The first case is that it is possible to reduce the dose\* and see an improvement in spatial resolution, while seeing lower image noise than the FBP scan. When using a configuration like the following, it is possible to see a 20% improvement in 50% MTF with the following comparison.

### iCT– Abdomen ExamCard

Parameter name	Parameter value FBP	Parameter value IMR
Collimation	128 x 0.625	128 x 0.625
Tube potential	120 kVp	120 kVp
Tube charge per slice	296 mAs	59 mAs
CTDI <sub>vol</sub>	20 mGy	4 mGy
Scan mode	Helical	Helical
Rotation time	0.75 s	0.75 s
Reconstruction mode	Standard	IMR
Level	N/A	3
Filter/image definition	A	Routine
Slice thickness	1.0 mm	1.0 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)
Matrix size	512 x 512	512 x 512

\* IMR is designed to reduce the dose required for diagnostic CT imaging. Image quality improvements and dose reduction depend on the clinical task, patient size, anatomical location, and clinical practice.

# iCT scanner

## Typical results seen for iCT

Scan #	MTF			Noise		
	FBP	IMR	% improvement	FBP	IMR	Ratio
1	2.874	3.870	+35%	7.1	4.2	-41%
2	2.773	3.975	+43%	6.3	3.4	-46%
3	2.886	4.321	+50%	6.0	3.9	-35%
4	2.820	4.198	+49%	6.1	3.8	-38%
5	2.850	4.256	+49%	6.3	3.7	-41%
<b>Average</b>			<b>+45%</b>			<b>-40%</b>

Note – The spatial resolution improves by over 40%, while the image noise decreases, even though the CTDI is 80% lower for IMR\*.

## Reduce dose\* and improve low-contrast resolution

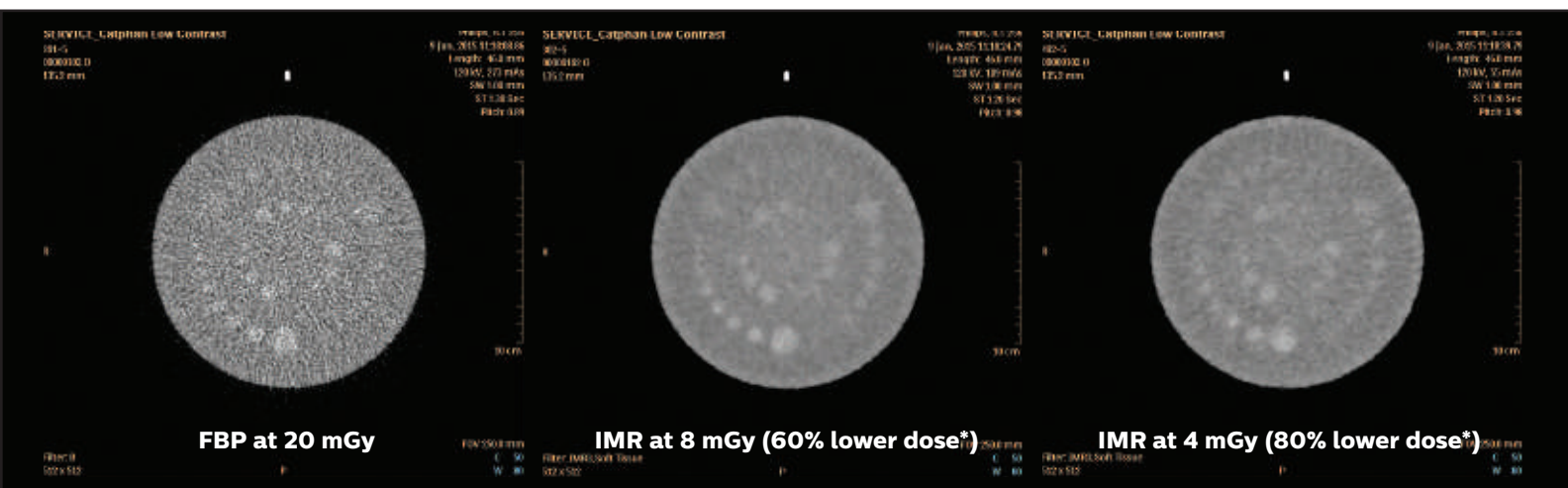
The second example of dose reduction\* considers low-contrast detectability. The Philips verification of this used a special image-quality phantom, developed by the MITA CT-IQ task force, and a detailed observer study. However, a special phantom is not needed to see that low-contrast detectability improves when using IMR and lower dose\*, and this is also seen with a standard Catphan.

Using a Catphan 600 phantom, scan the CTP515 low-contrast module of the phantom using the scan parameters in the chart in the next column.

## iCT – Abdomen ExamCard

Parameter name	Parameter value FBP	Parameter value IMR	
Collimation	128 x 0.625	128 x 0.625	128 x 0.625
Tube potential	120 kVp	120 kVp	120 kVp
Tube charge per slice	296 mAs	118 mAs	59 mAs
CTDI <sub>vol</sub>	20 mGy	8 mGy	4 mGy
Scan mode	Helical	Helical	Helical
Pitch	0.6 ± 0.1	0.6 ± 0.1	0.6 ± 0.1
Rotation time	0.75 s	0.75 s	0.75 s
Reconstruction mode	Standard	IMR	IMR
Level	N/A	3	3
Filter/image definition	B	Soft tissue and routine	Soft tissue and routine
Slice thickness	1.0 mm	1.0 mm	1.0 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)	Overlap (0.5 mm)
Window center/width	50/80	50/80	50/80
Matrix size	512 x 512	512 x 512	512 x 512

After the reconstructions have finished, observe the central slice of the low-contrast module. You should see more low-contrast pins in the IMR reconstructions (at lower dose\*) than in the standard (FBP) reconstruction. Examples are shown in **Figure 4**. More pins are visible in either IMR image than in the FBP image.



**Figure 4** Dose reduction\* and image quality with iCT.

\* IMR is designed to reduce the dose required for diagnostic CT imaging. Image quality improvements and dose reduction depend on the clinical task, patient size, anatomical location, and clinical practice.

# Basic testing

It is anticipated that the user adopting IMR may desire a means to understand the basic noise and spatial resolution trends of IMR. This section provides some comparative scans and reconstructions which demonstrate these trends. With this information, users can gain confidence in how IMR is working and allows them to focus on the adoption.

## Ingenuity scanner

### Noise and resolution vs. IMR image definition

With FBP reconstruction, the user can make a trade-off between image noise and spatial resolution by changing the reconstruction filter. With IMR, the user is able to overcome this trade-off to some extent.

To see that IMR is working in this sense, plan a series of reconstructions on the Ingenuity system phantom, head section and wires, with the following scan parameters.

Ingenuity	Abdomen Abdomen ExamCard	Head/Brain Helical	Chest High resolution Spiral ExamCard	Head/Sinus Facial bone
Parameter name	Parameter value standard resolution body	Parameter value standard resolution head	Parameter value high resolution body	Parameter value high resolution head
Collimation	64 x 0.625	64 x 0.625	64 x 0.625	64 x 0.625
Resolution (not displayed)	Standard	Standard	High	High
Tube potential	120 kVp	120 kVp	120 kVp	120 kVp
Tube charge per slice	300 mAs	300 mAs	300 mAs	300 mAs
CTDI <sub>vol</sub>	19.6 mGy	38.7 mGy	19.6 mGy	38.7 mGy
Scan mode	Helical	Helical	Helical	Helical
Rotation time	0.75 s	0.75 s	0.75 s	0.75 s

### All Image reconstructions should keep

Slice thickness	1 mm	1 mm	1 mm	1 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)	Overlap (0.5 mm)	Overlap (0.5 mm)
Matrix size	512 x 512	512 x 512	512 x 512	512 x 512

### Five different reconstructions per scan

Reconstruction mode	Standard	Standard	Standard	Standard
Filter	B	UB	B	UB
Reconstruction mode	Standard	Standard	Standard	Standard
Filter	YB	YB	YD	YD
Reconstruction	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	Soft tissue	Brain routine	Soft tissue	Brain routine
Reconstruction	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	Routine	Sharp	Routine	Sharp
Reconstruction	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	SharpPlus	SharpPlus	SharpPlus	SharpPlus

## Ingenuity scanner

After the reconstructions are complete, measure the image noise in the water part of the head section, and measure the MTF on the pin in the physics section. In general, the image noise and spatial resolution will increase as you change image definition.

As you move down the columns, the spatial resolution improves, and the IMR image noise is lower than the FBP image noise. Sometimes, the SharpPlus noise is higher than FBP with the UB filter, but is substantially lower than YB or YD filter, with about the same spatial resolution as those filters.

### Typical results seen for Ingenuity

	Body scans				Head scans			
	Standard		High		Standard		High	
	50% MTF	Noise	50% MTF	Noise	50% MTF	Noise	50% MTF	Noise
FBP – UB	2.927	10.5	3.576	16.1	2.889	5.4	2.954	6.4
IMR Soft Tissue	3.773	1.5	4.912	1.6	N/A	N/A	N/A	N/A
IMR Routine	4.809	2.8	5.410	2.8	3.195	1.9	3.385	1.8
IMR Sharp	N/A	N/A	N/A	N/A	4.403	2.2	4.321	3.1
FBP – YB/YD	7.117	89.0	6.513	64.5	6.798	49.2	6.110	29.6
IMR SharpPlus	7.557	10.2	7.531	9.4	6.782	12.4	6.470	8.4

# Ingenuity scanner

## Noise reduction compared with iDose<sup>4</sup>

The noise reduction in IMR was designed to start where iDose<sup>4</sup> ended. To see this, set up a scan of the system phantom (the body scans can include both the body and head sections, the head scans should be limited to the head section only), and the following series of reconstructions.

Ingenuity	Abdomen Abdomen ExamCard	Head/Brain Helical	Chest High resolution Spiral ExamCard	Head/Sinus Facial bone
Parameter name	Scan 1	Scan 2	Scan 3	Scan 4
Collimation	64 x 0.625	64 x 0.625	64 x 0.625	64 x 0.625
Resolution (not displayed)	Standard	Standard	High	High
Tube potential	120 kVp	120 kVp	120 kVp	120 kVp
Tube charge per slice	300 mAs	300 mAs	300 mAs	450 mAs
Pitch	0.80 ± 0.05	0.30 ± 0.05	0.80 ± 0.05	0.30 ± 0.05
CTDI <sub>vol</sub>	19.6 mGy	38.7 mGy	19.6 mGy	38.7 mGy
Scan mode	Helical	Helical	Helical	Helical
Rotation time	0.5 s	0.4 s	0.5 s	0.75 s
Slice thickness	1.0 mm	3 mm	0.67 mm	5 mm
Slice increment	Overlap (0.5 mm)	Overlap (1.5 mm)	Overlap (0.335 mm)	Overlap (2.5 mm)
Matrix size	512 x 512	512 x 512	512 x 512	512 x 512
Reconstruction 1	Standard	Standard	Standard	Standard
Filter	B	UB	B	UB
Reconstruction 2	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>
Level	1	1	1	1
Reconstruction 3	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>
Level	6	5	7	5
Reconstruction 4	IMR	IMR	IMR	IMR
Level	1	1	1	1
Image definition	Routine	Brain routine	Routine	Brain routine
Reconstruction 5	IMR	IMR	IMR	IMR
Level	2	2	2	2
Image definition	Routine	Brain routine	Routine	Brain routine
Reconstruction 6	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	Routine	Brain routine	Routine	Brain routine

## Ingenuity scanner

### The trend in the noise, measured at Philips

Ingenuity	Abdomen (300 mAs, 1 mm)		Thorax (300 mAs, 0.67 mm)		Head/Brain (300 mAs, 3 mm)	Head/Sinus (450 mAs, 5 mm)
	Aculon	Water (in head section)	Aculon	Water (in head section)	Water	Water
FBP – UB filter	32.5	10.3	44.2	13.9	4.4	2.8
iDose <sup>4</sup> – Level 1	28.6	9.3	38.9	12.5	4.0	2.7
iDose <sup>4</sup> highest level	17.9	5.8	19.6	6.3	2.9	2.0
IMR – Routine 1	12.3	5.6	11.0	5.4	2.4	1.7
IMR – Routine 2	8.2	4.2	7.5	4.0	2.0	1.5
IMR – Routine 3	4.8	2.9	4.5	2.8	1.7	1.3

In each case, IMR Level 1 has lower noise than iDose<sup>4</sup> at the highest level available for the scan type. And the noise from IMR gets even lower as the level increases from 1 to 3.

## iCT scanner

### Noise and resolution vs. IMR image definition

With FBP reconstruction, the user can make a trade-off between image noise and spatial resolution by changing the reconstruction filter. With IMR, the user is able to overcome this trade-off to some extent.

To see that IMR is working in this sense, plan a series of reconstructions on the iCT system phantom head and wires, with the following scan parameters.

iCT	Abdomen Abdomen ExamCard	Head/Brain Helical	Chest High resolution Spiral ExamCard	Head/Sinus Facial bone
Parameter name	Parameter value standard resolution body	Parameter value standard resolution head	Parameter value high resolution body	Parameter value high resolution head
Collimation	64 x 0.625	64 x 0.625	64 x 0.625	64 x 0.625
Resolution (not displayed)	Standard	Standard	High	High
Tube potential	120 kVp	120 kVp	120 kVp	120 kVp
Tube charge per slice	300 mAs	300 mAs	300 mAs	300 mAs
CTDI <sub>vol</sub>	20.3 mGy	41.4 mGy	19.2 mGy	40.8 mGy
Scan mode	Helical	Helical	Helical	Helical
Rotation time	0.75 s	0.75 s	0.75 s	0.75 s

### All image reconstructions should keep

Slice thickness	1 mm	1 mm	1 mm	1 mm
Slice increment	Overlap (0.5 mm)	Overlap (0.5 mm)	Overlap (0.5 mm)	Overlap (0.5 mm)
Matrix size	512 x 512	512 x 512	512 x 512	512 x 512

### Five different reconstructions per scan

Reconstruction mode	Standard	Standard	Standard	Standard
Filter	B	UB	B	UB
Reconstruction mode	Standard	Standard	Standard	Standard
Filter	YB	YB	YD	YD
Reconstruction	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	Soft tissue	Brain routine	Soft tissue	Brain routine
Reconstruction	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	Routine	Sharp	Routine	Sharp
Reconstruction	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	SharpPlus	SharpPlus	SharpPlus	SharpPlus



## iCT scanner

After the reconstructions are complete, measure the image noise in the water part of the head section, and use the image tools to measure the MTF of the pin in the physics section. In general, the image noise and spatial resolution will increase as you change image definition.

As you move down the columns, the spatial resolution improves, and the IMR image noise is lower than the FBP image noise. Sometimes the SharpPlus noise is higher than FBP with the UB filter, but is substantially lower than YB or YD filter, with about the same spatial resolution as those filters.

### Typical results seen for iCT

iCT	Body scans				Head scans			
	Standard		High		Standard		High	
	50%	Noise	50%	Noise	50%	Noise	50%	Noise
FBP – UB	3.284	9.9	3.922	15.5	3.052	5.3	3.298	6.9
IMR Soft Tissue	3.976	1.5	5.163	1.7	N/A	N/A	N/A	N/A
IMR Routine	5.042	2.9	5.550	2.9	3.266	1.9	3.695	2.0
IMR Sharp	N/A	N/A	N/A	N/A	4.705	2.2	4.847	2.3
FBP – YB/YD	5.989	72.2	5.847	62.4	5.997	45.3	6.098	32.2
IMR SharpPlus	6.257	9.4	5.972	9.5	5.943	11.9	6.093	9.0

## iCT scanner

### Noise reduction compared with iDose<sup>4</sup>

The noise reduction in IMR was designed to start where iDose<sup>4</sup> ended. To see this, set up a scan of the system phantom (either head or body, depending on the scan), and the following series of reconstructions.

iCT	Abdomen Abdomen ExamCard	Chest High resolution Spiral ExamCard	Head/Brain Helical	Head/Brain Helical
Parameter name	Scan 1	Scan 2	Scan 3	Scan 4
Collimation	64 x 0.625	64 x 0.625	64 x 0.625	64 x 0.625
Resolution (not displayed)	Standard	High	Standard	High
Tube potential	120 kVp	120 kVp	120 kVp	120 kVp
Tube charge per slice	300 mAs	300 mAs	300 mAs	450 mAs
Pitch	0.80 ± 0.05	0.80 ± 0.05	0.30 ± 0.05	0.30 ± 0.05
CTDI <sub>vol</sub>	20.3 mGy	19.2 mGy	41.4 mGy	40.8 mGy
Scan mode	Helical	Helical	Helical	Helical
Rotation time	0.5 s	0.5 s	0.4 s	0.75 s
Slice thickness	3.0 mm	0.67 mm	3 mm	5 mm
Slice increment	Overlap (1.5 mm)	Overlap (0.335 mm)	Overlap (1.5 mm)	Overlap (2.5 mm)
Matrix size	512 x 512	512 x 512	512 x 512	512 x 512
Reconstruction 1	Standard	Standard	Standard	Standard
Filter	B	B	UB	UB
Reconstruction 2	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>
Level	1	1	1	1
Reconstruction 3	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>	iDose <sup>4</sup>
Level	6	7	5	5
Reconstruction 4	IMR	IMR	IMR	IMR
Level	1	1	1	1
Image definition	Routine	Routine	Brain routine	Brain routine
Reconstruction 5	IMR	IMR	IMR	IMR
Level	2	2	2	2
Image definition	Routine	Routine	Brain routine	Brain routine
Reconstruction 6	IMR	IMR	IMR	IMR
Level	3	3	3	3
Image definition	Routine	Routine	Brain routine	Brain routine

## iCT scanner

### The trend in the noise, measured at Philips

iCT	Abdomen (300 mAs, 3 mm)	Thorax (300 mAs, 0.67 mm)	Head/Brain (300 mAs, 3 mm)	Head/Sinus (450 mAs, 5 mm)
	Body phantom	Body phantom	Head phantom	Head phantom
FBP – UB filter	13.1	53.4	3.6	2.8
iDose <sup>4</sup> – Level 1	11.7	46.5	3.3	2.7
iDose <sup>4</sup> highest level	7.3	29.3	2.4	2.0
IMR – Routine 1	6.9	16.5	2.0	1.8
IMR – Routine 2	5.2	10.4	1.7	1.6
IMR – Routine 3	3.8	5.4	1.5	1.4

In each case, IMR Level 1 has lower noise than iDose<sup>4</sup> at the highest level available for the scan type. And the noise from IMR gets even lower as the level increases from 1 to 3.

# Image quality trends

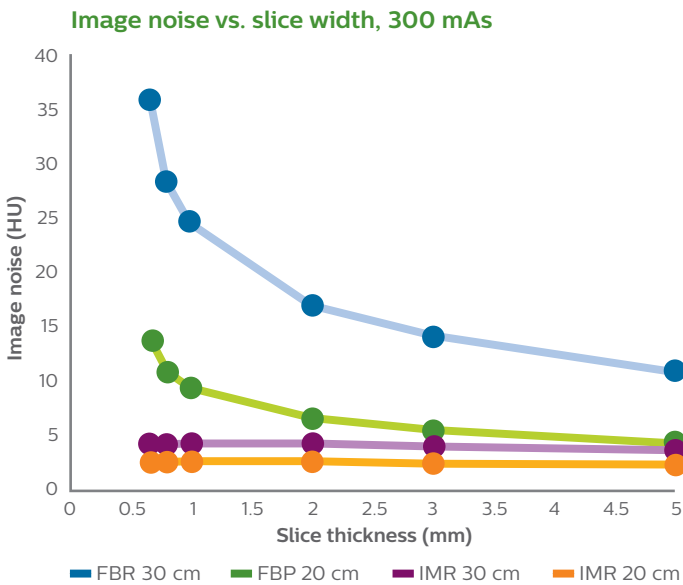
While the performance metrics characterize performance at an optimized limit where the performance is maximized, and the basic testing describes means by which the noise and spatial resolution performance can be understood, the image quality trends section describes how key image quality metrics vary across operating conditions. With this information, users have a data-driven framework and confidence that allows them to develop an adoption strategy appropriate for their particular circumstances.

The behavior of image noise with IMR reconstructions is very different from what users may be accustomed to with FBP or iDose<sup>4</sup>. With FBP, the noise scales in well-documented ratios as the slice thickness and mAs are varied. Water equivalent

diameter (WED) can be considered as a proxy for patient size. As the WED increases, the noise increases close to exponentially. When applying iDose<sup>4</sup> to any of these scans, the noise changes in a well-defined ratio at each level of iDose<sup>4</sup>.

In contrast, IMR works to remove as much noise as possible from each image. As the slice thickness or mAs vary, the noise does not change in proportion to the FBP noise. As the water equivalent diameter increases, the noise increases, but not as much as with FBP.

At Philips, a series of cylindrical water phantoms were scanned at different mAs settings and for a range of slice thicknesses from 0.67 mm up to 5 mm to demonstrate these trends.

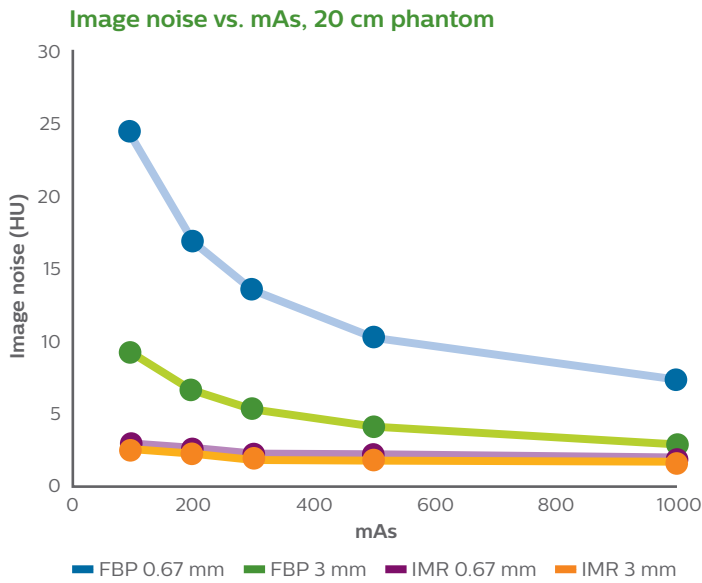


## Image noise vs. slice width

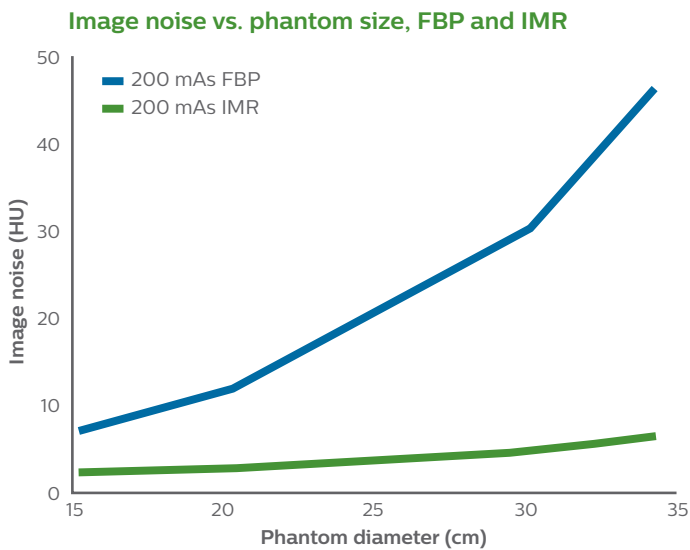
With FBP, it is well-known that the image noise is proportional to the inverse of the square root of the slice thickness. Thus, for a given reconstruction, to cut the image noise in half the slice thickness needs to be increased by a factor of four. To see this, consider this graph in **Figure 5** that shows image noise vs. slice thickness for two different-sized cylindrical phantoms at 300 mAs.

The FBP image noise does drop off as the slice thickness increases. In contrast, IMR noise stays close to constant, even as the slice thickness increases. Note that the highest noise seen for these scans with IMR is less than 5 HU, and that the range of noise for both phantom sizes is very small. Thus, the expected noise reduction varies with the slice thickness – there is more noise reduction with thin slices than with thick slices.

**Figure 5** Image noise for FBP and IMR reconstruction vs. slice thickness for 20 and 30 cm diameter phantoms.



**Figure 6** Image noise for FBP and IMR reconstruction vs. mAs for a 20 cm phantom.



**Figure 7** Image noise vs. phantom size, for both FBP and IMR.

### Image noise vs. mAs

Similarly, with FBP, it is well-known that the image noise is proportional to the inverse of the square root of the dose, or mAs. Thus, for a given reconstruction, to cut the image noise in half the mAs needs to be increased by a factor of four. To see this, consider this graph in **Figure 6** that shows image noise vs. mAs for a 20 cm cylindrical phantom.

Just like the previous case, the FBP image noise does drop off as the mAs increases. The IMR image noise is close to constant, and hardly varies with mAs. In this case, the highest IMR noise seen for these scans is less than 3.5 HU. Thus, the expected noise reduction varies with mAs (or dose) – there is more noise reduction with small values of mAs (dose) compared with high values of mAs (dose).

### Image noise vs. Water Equivalent Diameter

As the WED gets larger, the image noise from FBP also gets larger, when all other parameters are kept constant. **Figure 7** shows the noise from different-sized phantoms, at 200 mAs and with 1 mm SW.

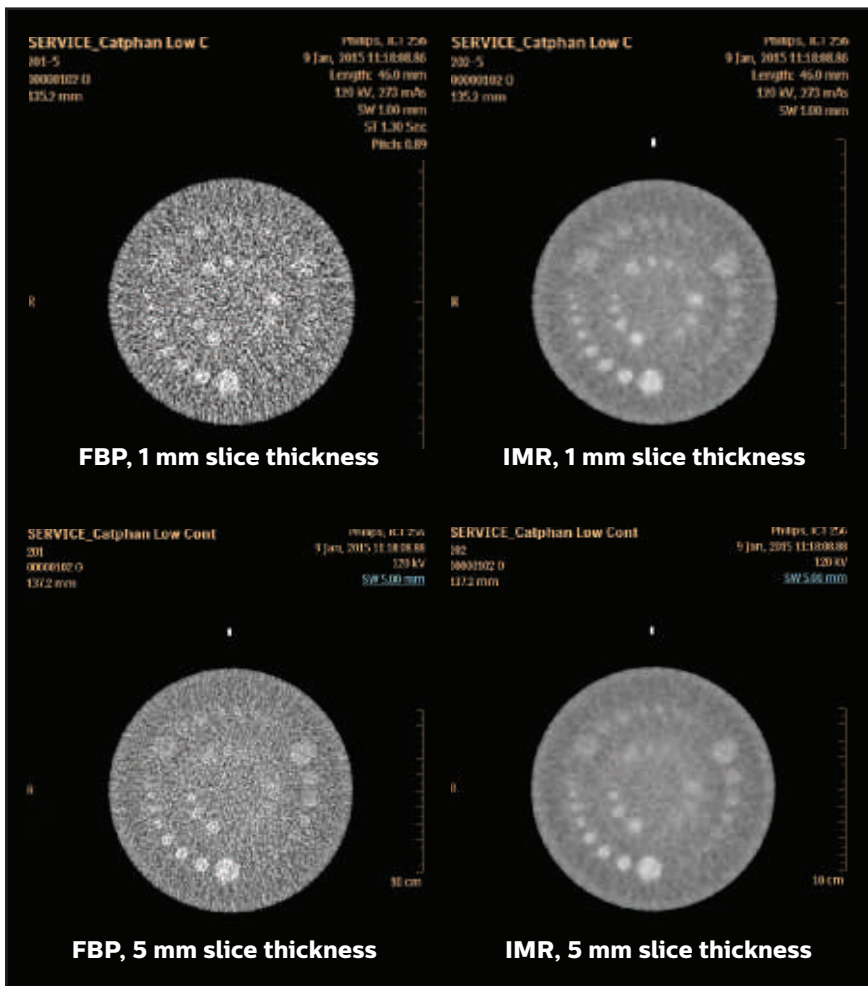
The graphs are roughly linear with a logarithmic scale on the y-axis, which suggests an exponential dependence. When this is scaled out, the FBP scaled noise appears roughly flat, but the IMR scaled noise decreases as the phantom size increases. Thus, the expected noise reduction varies with WED – unlike the previous cases, there is more noise reduction with large values of WED than with smaller values.

### Combined impact on noise reduction ratios

Since the image noise variation with IMR is so different from FBP, the noise reduction ratio can vary with slice thickness, mAs (dose) and body size. For large patients, and thin slice scans, there can be a very high noise reduction when IMR is used. For smaller patients or thicker slices (for example, a pediatric or adult head scan), the noise reduction is considerably lower. Note that IMR can allow a physician to scan head scans with thin slices, and still have low noise images, compared with FBP and 5 mm slices.

### Effect on low-contrast resolution

Often, users will need to increase slice thickness to improve low-contrast resolution. With IMR, there is usually not much benefit to this approach, since even thin slices have low noise. An example is shown in **Figure 8**. Increasing the slice thickness from 1 mm to 5 mm improves low-contrast resolution for FBP, but not for IMR.



**Figure 8** Low contrast at 20 mGy.

# Special considerations

IMR has special considerations for the way that noise may manifest as artifacts. There are CT artifacts that are made more apparent when the image noise is reduced. This section illustrates some of the artifacts of which the audience should be made aware.

IMR is available for all helical and 3D axial protocols except scans using UltraHigh Resolution (UHR). IMR is blocked for some axial scans listed below.

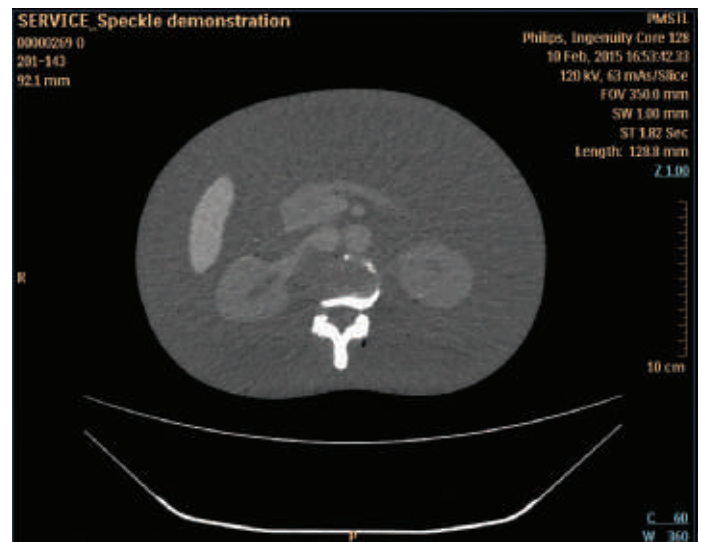
- IMR needs a slice overlap between images, which is not available in 2D reconstructions. Therefore, IMR is not available for:
  - Brain 2D
  - Calcium Score 2D
  - CCT
  - 2 x 0.625 (e.g., axial HR lung and HR sinus)
  - Locator and tracker scans
- Note: there are protocols for Calcium Score 3D and Brain Helical which have IMR enabled.
- IMR was not configured for UHR helical or axial scans.

## Shapes and rough feature edges

- With higher noise images, the eye naturally fills in the boundaries between different regions as a continuous line. When the noise is reduced, the remaining noise can give the boundaries a stair-step or rough appearance.
- It is impossible to remove noise, and not change “shape,” because “shape” is dependent on how the object + noise intersects with the chosen window and level setting.
- In the presence of noise, it is difficult to know which depiction (FBP, iDose<sup>4</sup> or IMR) is closer to the object ground truth. There is a good probability that it is IMR, based on the obvious noise removal in the background, but there is no way to say for sure on any given image.
- The smaller the object is, the higher the probability the shape is affected by noise.

## Speckle noise

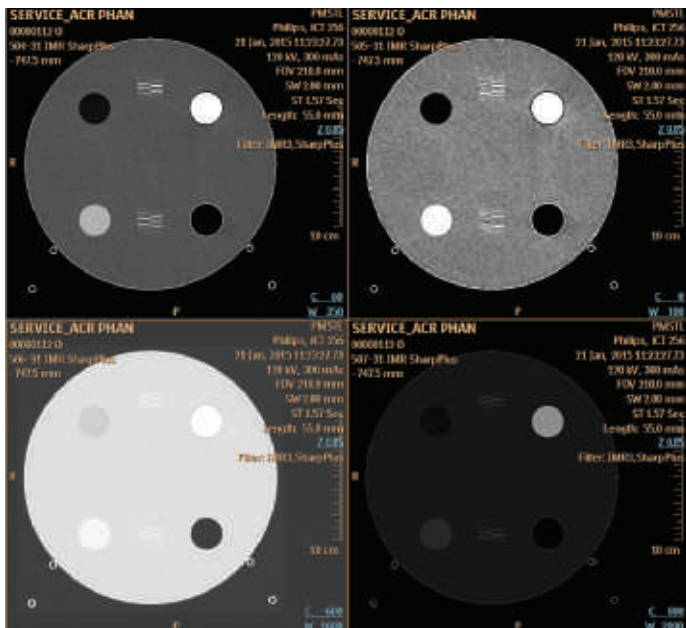
- IMR assumes that the noise level in adjacent slices is similar. This assumption breaks down at each end of a helical scan, where the slice before the first or after the last slice has no noise (and no image) at all. As a result, sometimes an artifact can appear as white or black speckles in the first and last slices. When these speckles appear, they are obvious, and disappear within a few slices of the ends of the helical scan. They do not appear with thicker slices.
- An example is shown in **Figure 9**.



**Figure 9** Speckle noise in an end slice.

### Brightening of edges with SharpPlus

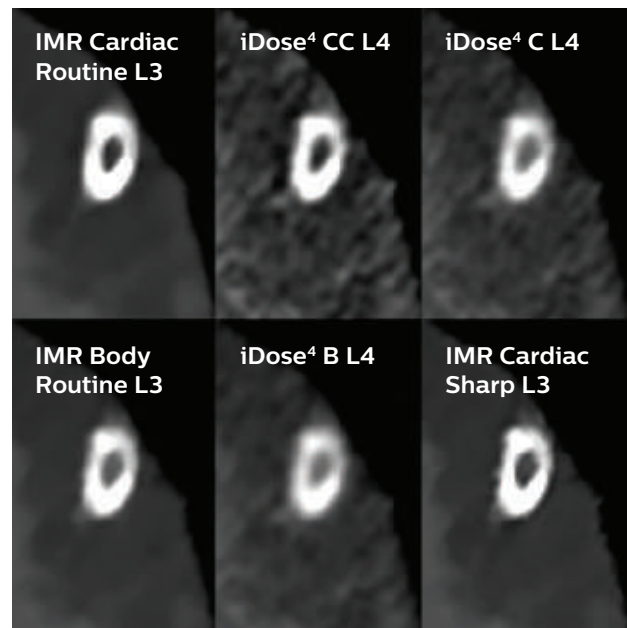
- With narrower window settings, it is possible to see overshoots and undershoots at tissue boundaries when using IMR SharpPlus. This can also be seen in standard reconstruction with certain filters (e.g., YB, YC). As with those filters, Philips suggests that you limit SharpPlus reconstructions to wider visualization windows (e.g., bone or lung windows). In addition these overshoots and undershoots will proliferate through the volume in some visualization modes such as MIP and MinIP reconstructions.



**Figure 10** Example of brightening at boundaries, and noting that brightening is less visible when using lung or bone window settings (lower row).

### Hypodensities with cardiac stents

- IMR provides a different representation of CT number inside stents than FBP or iDose<sup>4</sup> do. FBP and iDose<sup>4</sup> can also show different CT numbers with the same data. Appearance can be different from old images.



**Figure 11** Reconstructions of a stent.



### MTF at low dose

- FBP is a linear algorithm. As such, the contrast measurements used for MTF measurements are largely independent of dose. Since MTF measurements are typically made on a high-contrast wire, the contrast is much higher than the image noise, and the measured values do not change much as the dose of the test scan is decreased. IMR is a non-linear algorithm. As the dose gets very low, it has trouble maintaining the measured MTF values. This can be seen with the following experiment:
- Align a Catphan off the end of the couch, and add an elliptical body ring (CTP579) or circular body ring (CTP539) over the tungsten wire module (CTP591). Scan the Catphan with a reference abdomen protocol, but with a 1 mm slice thickness. Repeat the scan, changing the mAs from the default to lower and lower values. For each scan, perform two reconstructions, one with the B Filter, and the second with IMR Routine, Level 3. Stop scanning at about 50 mAs, where the image gets too noisy even for FBP to work reliably. At Philips, five measurements at each mAs were taken, and the results were averaged, giving a graph that looks like the following.

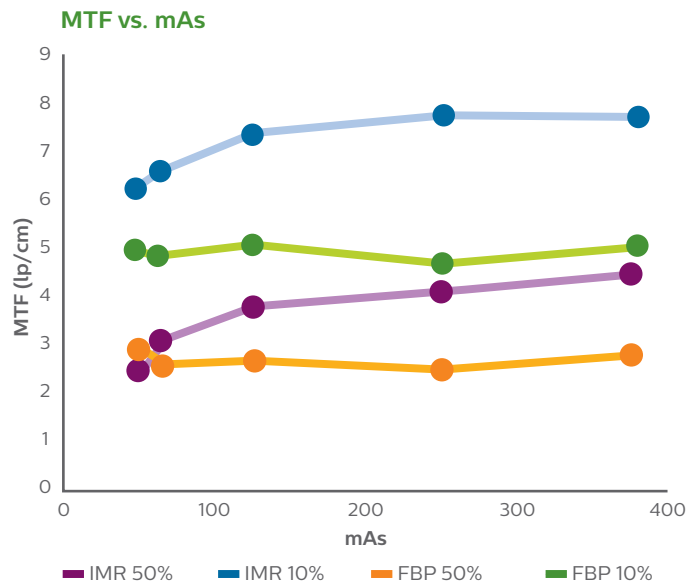


Figure 12 MTF vs. mAs for both FBP and IMR.

### Ingenuity – elliptical body ring

mAs	IMR	IMR	FBP	FBP
	50% MTF	10% MTF	50% MTF	10% MTF
381	4.4092	7.6464	2.7378	4.9842
254	4.0344	7.6554	2.4108	4.6416
127	3.7564	7.3176	2.6108	5.0428
64	3.0634	6.5278	2.5216	4.8216
50	2.4760	6.2130	2.8294	4.9580

IMR shows a loss of MTF as the mAs decreases, but is always above the B filter, except at 50 mAs, where the B filter shows too much variation at this high noise setting to give a reliable measurement.

# Appendix

Physicists use several different methods to characterize image quality. The metrics used in this paper are summarized below.

## Image noise

Image noise is a measure of statistical fluctuations in the image.

[2] It is a consequence of a variety of statistical processes that occur in the attenuation and detection of X-rays by a CT system, but the dominant source is the quantum fluctuations in X-rays.

An X-ray tube will not emit an exact number of X-rays over a given time period, but rather the number of X-rays will fluctuate about some mean value according to a Poisson distribution.

Noise is measured by calculating the standard deviation of pixel values in an ROI of a uniform section of a phantom. The IEC recommends using an ROI with diameter equal to 40% of the phantom diameter. For 30 cm phantoms, this is 11,000 mm<sup>2</sup> and for 20 cm phantoms, this is 5000 mm<sup>2</sup>.

## High-contrast spatial resolution improvement

High-contrast spatial resolution is a measure of an imaging system's ability to preserve the spatial information in a high-contrast object and accurately represent it in the image. It is expressed in terms of the modulation transfer function (MTF). [3] Many factors influence the high-contrast spatial resolution, including the design of the X-ray tube and detector, as well as the reconstruction algorithm. Traditional trade-offs between noise and spatial resolution in computed tomography exist via the reconstruction filter. In FBP, smoother filters can be used to produce images with less noise, but with reduced spatial resolution. With IMR, noise is reduced while simultaneously improving high-contrast spatial resolution. Unlike FBP, for IMR, being a "non-linear" reconstruction algorithm, the spatial resolution may depend on the contrast of the object. That is, the spatial resolution of high-contrast objects may in principle be different from the spatial resolution of low-contrast objects. On Philips scanners, MTF can be measured with a high-contrast pin, using the Image Tests/Resolution Tests available in the analysis options on the image viewer screen.

## Low-contrast resolution

Low-contrast resolution is a measure of the ability to distinguish a low-contrast object from its background.[3] Low-contrast resolution is measured with a Catphan® 600 module CTP515, using a helical scan with a Window setting close to the CT number values of the low-contrast pins. Low-contrast resolution is usually expressed as the smallest visible pin at a specific contrast level, at the scanned CTDI. When reconstructing the same data set with FBP and IMR, the low-contrast resolution is improved because the image noise is reduced.

## Low-contrast detectability

Low-contrast detectability (LCD) is a measure of a person's ability to perform a particular task: the detection of a low-contrast object. LCD is influenced to some degree by all of the image quality metrics discussed previously, as well as the reaction of the human visual perception system to those factors. Due to the influence of noise, and the fact that the exact appearance of noise changes from one scan to the next, accurately capturing the influence of noise on LCD requires a statistical approach. In other words, LCD cannot be assessed from a single image, but rather an ensemble of images must be used to characterize the average performance. To assess the impact of IMR on low-contrast detectability, it was measured by a method known as a human observer study. This is a new phantom and bench testing methodology that the industry is moving towards for assessing LCD.[4] In this method, a cohort of human test subjects is asked to perform a low-contrast detectability task on a set of repeated scans of a phantom. The particular method employed is known as an alternative forced-choice human observer test.[5] From the average ratio of correct responses, a quantity known as the detectability index can be calculated. The detectability index is a dimensionless quantity that characterizes the degree to which subjects can distinguish images with the low-contrast object present from those with it absent. The detectability index ranges from 0, where subjects have no ability to distinguish the low-contrast object, to higher values representing improvement in low-contrast detectability.

\* IMR is designed to reduce the dose required for diagnostic CT imaging. Image quality improvements and dose reduction depend on the clinical task, patient size, anatomical location, and clinical practice.

## References

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