High resolution for improved visualization on new mobile X-ray systems Optima XR240amx

X-ray Engineering white paper

Authors

Matthieu Guillard, MSc, Image Quality Senior Engineer
Ping Xue, PhD, Image Quality Principal Engineer
German Vera, MSc, Image Quality Engineering Manager

Abstract

GE's new mobile X-ray system Optima XR240amx is introducing the FlashPad HD wireless cassette-size digital flat panel detectors with an 100μm pixel pitch and an improved pixel design. It provides a higher spatial resolution and a higher detection efficiency at all frequencies and all dose levels when compared to Optima XR220amx, which justify the use of smaller pixel size.

Characterization of these improvements is realized using industry standard detector performances metrics (DQE, MTF, limiting resolution) and a study of Contrast Detail phantom for which the detectability of small objects is especially increased.

Helix, the digital image processing of Optima XR240amx system, is optimized to take advantage of the additional high resolution content in the raw image for the display of a sharper processed image compared with Optima XR220amx. The benefit is illustrated with clinical images for extremities exam and line placement assessment for which high resolution is a key element of clinical diagnosis.

Note: Optima XR200amx and Optima XR220amx systems can be upgraded to Optima XR240amx system with FlashPad HD detectors.

Background

The mobile X-ray market is in transition as customers move from traditional screen film based detectors and CR detectors to wireless digital X-ray detectors allowing near instantaneous image display, digital image processing and advanced applications. Cassette size detectors for mobile systems are 14" by 17" (35x43 cm) and 10" by 12" (25x30 cm). Data provided in this document is measured on 14" by 17" detectors, performance of the 10" by 12" detector is identical.

Detector parameters comparison

In this paper, the Optima XR240amx system is compared with the previous Optima XR220amx system both equipped with a digital flat panel detector. The Optima XR240amx system introduces the FlashPad HD detector with a smaller pixel pitch of 100µm while the pixel pitch of Optima XR220amx's FlashPad is 200µm.

Reduction of pixel size increased the Modulation Transfer Function (MTF) thanks to a finer spatial sampling of the signal. Additionally, the impact of pixel size on noise can theoretically be described as follows: considering the same input X-ray signal and a detector 1 with a pixel size of 200µm and a detector 2 with a pixel size of 100µm, the intensity of a 200µm pixel I_1 is:

$$I_1 = S_1 \pm \sqrt{\sqrt{S_1}^2 + en_1^2} \qquad (1)$$

With S_1 the X-ray signal, $\sqrt{S_1}$ the quantum noise and en_1 the pixel electronic noise. The intensity of a 200µm pixel I_2 is:

$$I_2 = S_2 \pm \sqrt{\sqrt{S_2}^2 + en_2^2} \qquad (2)$$

To display the same anatomical feature, detector 1 would use N_1 pixels while detector 2 will use $4*N_1$ pixels. A fair comparison shall be to consider the signal per physical area and not per pixel. The signal I'_2 of 4 pixels of 100µm is:

$$I'_2 = 4 * S_2 \pm \sqrt{\sqrt{S_2}^2 + \sqrt{S_2}^2 + \sqrt{S_2}^2 + \sqrt{S_2}^2 + en_2^2 + en_2^2 + en_2^2 + en_2^2}$$

$$I'_2 = S_1 + \sqrt{\sqrt{\frac{S_1}{4}}^2 + \sqrt{\frac{S_1}{4}}^2 + \sqrt{\frac{S_1}{4}}^2 + \sqrt{\frac{S_1}{4}}^2 + 4\, en_2^2}$$

$$I'_2 = S_1 + \sqrt{\sqrt{S_1}^2 + 4\, en_2^2} \qquad (3)$$

Equation (1) and (3) show that the X-ray signal and quantum noise are independent of pixel size; the difference is in the pixel electronic noise appearing with a higher weight for the smaller pixel size detector.

The FlashPad HD electronic design improves the pixel noise performance reducing the electronic noise per pixel versus FlashPad which makes en_2 lower than en_1, moreover improvement on X-ray signal conversion is also realized allowing to convert more efficiently X-ray signal into pixel intensity. Detective Quantum Efficiency (DQE) is a metric considering all these variables and is the most recognized and standardized method for detector performance characterization [1], [2]. As part of Optima XR240amx pilots installation, the lowest clinical detector average entrance dose was observed for small pediatrics patient and was in the order of magnitude of 1µGy, which is consistent with literature [3], [4]. As shown on fig. 1 the DQE of FlashPad HD detector is higher than FlashPad detector at all dose levels. As per product data sheet, the high dose DQE at 0 lp/mm is 68% for FlashPad and 75% for FlashPad HD, resulting in a 10% increase.

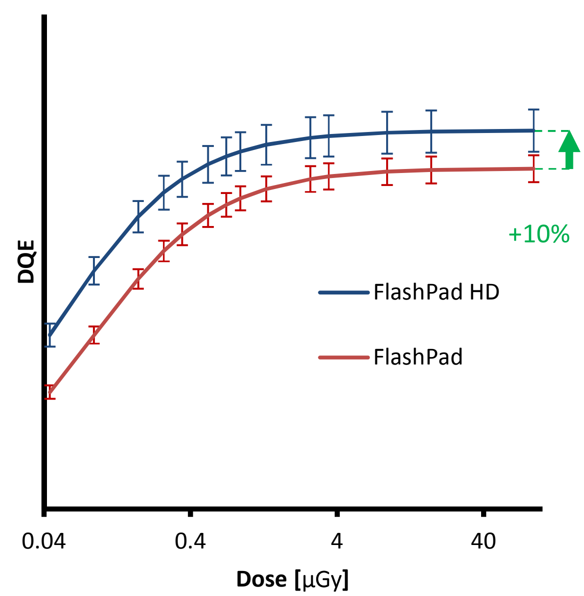


***Fig. 1**: DQE at 0lp/mm vs dose of FlashPad and FlashPad HD detectors*

The DQE improvement at low and high dose (fig. 1) and low and high frequency (fig. 2) demonstrates that the improvement in pixel design compensate the theoretical noise increase to fully take advantage of the higher MTF. As shown on fig. 2, the low frequency performances of the two detector versions are comparable. At high frequency, the efficiency of the FlashPad HD detector is increased and allows the detection of additional signal that is not detected by FlashPad detector. Detector with 100µm pixel pitch provides a Nyquist frequency at 5lp/mm (cutoff in DQE curve in fig. 2) and has less artifact due to aliasing as seen in fig. 3. Higher frequency noise inherent to the signal is also detected giving a visual difference as seen in fig. 3.

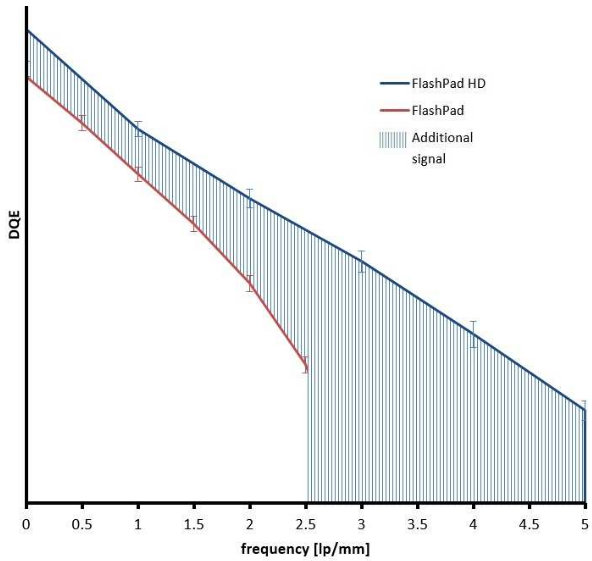


Fig. 2: *DQE at 0.35µGy vs frequency of FlashPad and FlashPad HD detectors*

The detection of this high frequency signal can be easily illustrated by imaging a spatial resolution test pattern which consists of a pattern of lead strips, of different widths and distances in between (different spatial frequencies), sandwiched between plastic plates. Fig. 3 shows a resolution test pattern for which the frequency of 5lp/mm is visible on Optima XR240amx system while Optima XR220amx system is not able to detect this signal. Fine lead lines appear blurred on the left image while they can be distinguished on the right image. The spatial limiting resolution is the highest spatial frequency detectable by the system. The theoretical spatial limiting resolution, linked to pixel size sampling, in vertical or horizontal direction is 5lp/mm for Optima XR240amx system and 2.5lp/mm for Optima XR220amx system. The limiting spatial resolution in diagonal direction, exceeding the resolution in vertical and horizontal direction, is measured with a resolution test pattern at [5.6-6.3] lp/mm for Optima XR240amx system and [2.5-2.8] lp/mm for Optima XR220amx system. The resolution is increased by a factor of 2 between Optima XR240amx and Optima XR240amx systems.

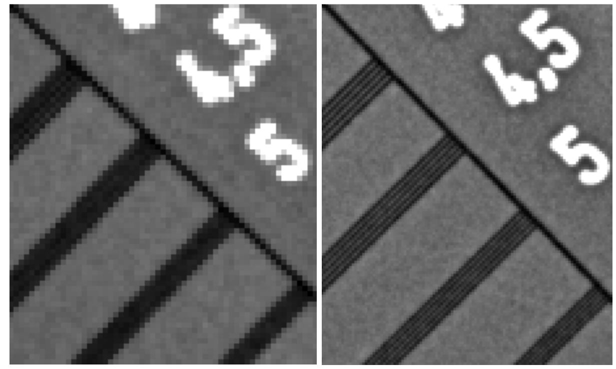


Fig. 3: *Resolution test pattern image, left Optima XR220amx, right Optima XR240amx*

Additionally, the bit depth is higher on Optima XR240amx (16bits) than Optima XR220amx (14bits).

Detectability study with Contrast Detail phantom

The Image Quality (IQ) is assessed in this section by measuring the visibility of small and large targets of low and high contrast under different clinically relevant conditions. Such Contrast Detail (CD) analysis is commonly used to assess Image Quality and has good correlation with clinical image review by radiologist for chest images [5]. The detection capability of the Optima XR220amx system and Optima XR240amx system are compared using the Artinis Medical Systems CDRAD 2.0 phantom. The phantom consists of a 265x265x10mm PMMA (Poly (methyl methacrylate)) tablet with a matrix of 15 columns and 15 rows containing cylindrical holes with variable diameter and depth. The diameter of the holes decreased from top to left and the depth of the holes decrease from right to left. The less detectable holes are thus on the bottom left corner of the image as can be seen in fig. 4. The top right region of the CDRAD phantom corresponds to large object with high contrast easily detectable, the top left region corresponds to large object with low contrast and the bottom right corresponds to small object with high contrast. The CD curve, delimiting visible and non-visible objects, and the inverse of Image Quality Figure (IQF inv, index of image quality), computed using equation (4), are used to assess Image Quality. High detectability of a system corresponds to high IQF inv index.

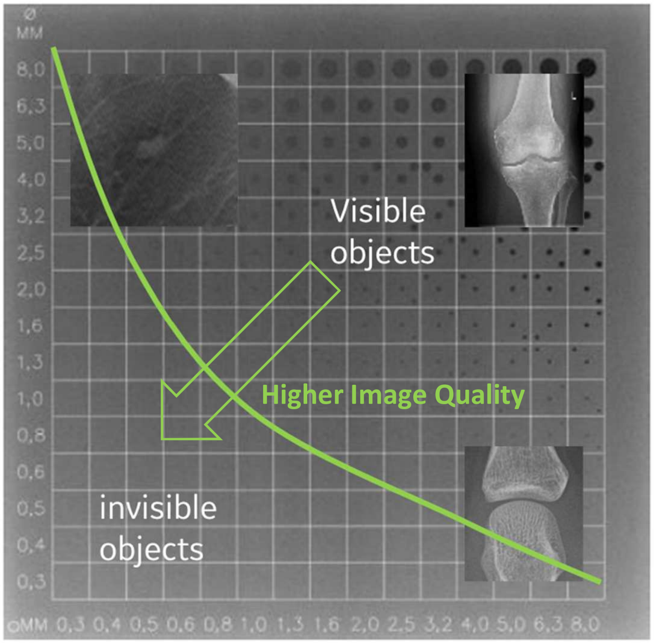


***Fig. 4**: CDRAD phantom*

$$IQFinv = \frac{100}{\sum_{i=1}^{15} C_i \cdot D_{i,th}} \qquad (4)$$

Di = diameter of hole [mm] (Detail)
Ci = depth of hole [mm] (Contrast)

To represent a range of clinical applications the CDRAD phantom was placed between additional plates of PMMA following the three conditions shown in fig. 5. Condition 1 with CDRAD phantom without additional filtration represents thin anatomies (extremities, pediatrics), condition 2 with 10cm PMMA filtration represents intermediate anatomies (C-spine, lower extremities) and condition 3 with 20cm PMMA represents thicker anatomies (Abdomen, Chest).

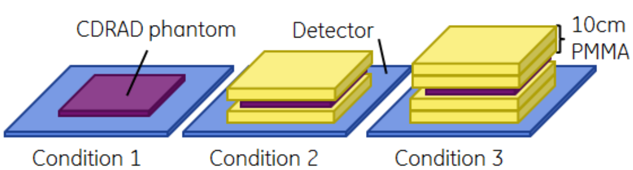


***Fig. 5**: Study conditions with CDRAD phantom*

For condition 1 and 2, no grid is used and the source to image distance (SID) is set to the detector gain calibration condition of 120cm. For condition 3, an anti-scatter grid is used, 70lp/cm, 8:1 ratio and the SID is set to the grid focal distance of 130cm. For each mAs value 10 images are used for the CD curve and IQF inv computation. The image processing parameters used for each condition is system Factory 1. Hand PA protocol is used for condition 1, Thoracic-spine AP protocol is used for condition 2 and chest AP protocol is used for condition 3.

The analysis software CDRAD Analyzer V2.1.15 developed by Artinis Medical Systems for their CDRAD 2.0 phantom is used to automatically compute CD curve and IQF inv. Two statistical values can be adjusted by the user, the a-priori-difference-of means (APD) and the significance level (α). The APD is set relatively to the image depth, 4 for Optima XR240amx and 1 for Optima XR220amx. A calibration of CDRAD Analyzer software is performed to set the significance level. The correlation of human observer with software for review of CDRAD images is analyzed by the review of 6 different images for each system representing the diversity of setup and dose level (second highest and second lowest dose level for each condition) by 3 human reviewers. For each image the human observer result is compared with software result obtained with different significance level alpha values to determine the significance level alpha matching the human observer result as shown on fig. 6.

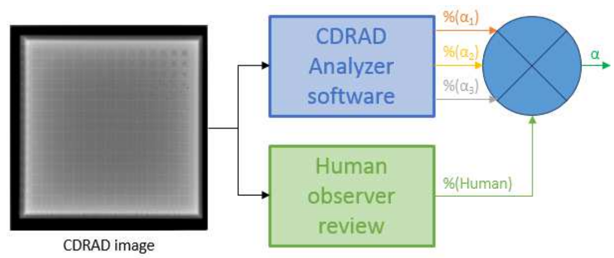


***Fig. 6**: Schematic of the process used to determine the parameter of the CDRAD Analyzer software: the significance level alpha*

For Optima XR220amx system the significance level is set to 1E-2 and for Optima XR240amx it is set to 1E-4 to fit the average of human observer review results similarly to [6] as can be seen in fig. 7.

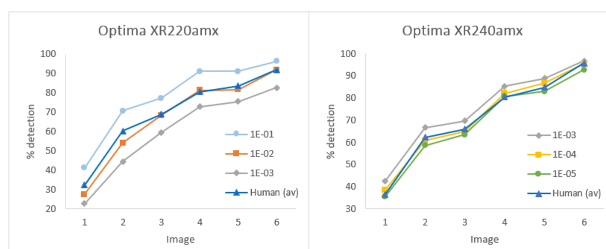


***Fig. 7**: Correlation between human observer (average) and software CDRAD Analyzer V2.1.15 for different significance levels*

Fig. 8 shows an example of CD curve with the same significance level displaying the improvement in detectability for all hole diameters and depth. Using the same significance level overestimate the difference between the two systems compared to human review.

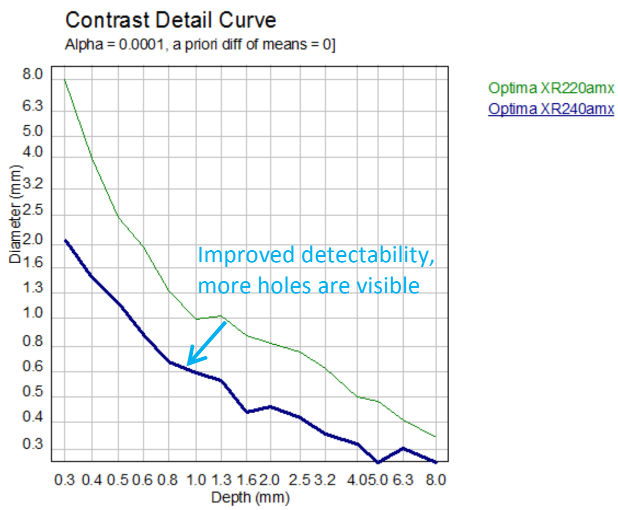


Fig. 8*: Example of Contrast Detail curve at 0.2mAs, condition 1 (no PMMA), 60kV, SID 120cm, 10 images for computation with same significance level*

For each study condition, a wide range of tube currents is used to represent a large range of clinical applications, demonstrating the image quality improvement at all relevant dose levels. Fig. 9, 10 and 11 show the IQFinv results for conditions 1, 2 and 3 respectively. For condition 1 the CDRAD phantom is almost entirely visible with Optima XR220amx system as seen for image 5 and 6 in fig.7, the CDRAD phantom shows limitation to measure the improvement of Optima XR240amx system in this condition.

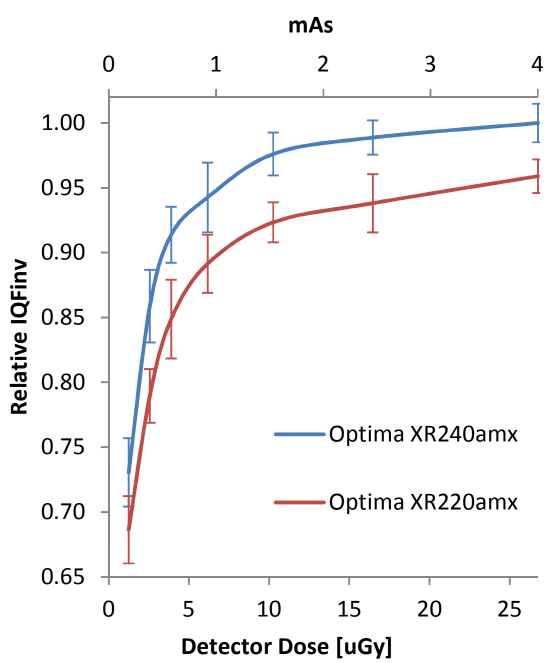


Fig. 9*: Relative IQFinv of Optima XR240amx and Optima XR220amx systems for condition 1: no additional PMMA filtration, 60kV, SID 120cm*

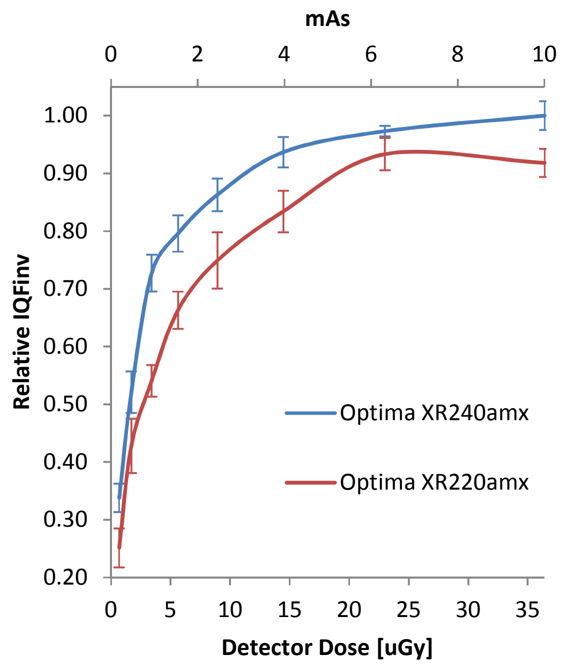


Fig. 10*: Relative IQFinv of Optima XR240amx and Optima XR220amx systems for condition 2: 10cm additional PMMA filtration, 80kV, SID 120cm*

For a clinically relevant exposure settings of a chest X-ray in condition 3 (120kVp, 1mAs) the detectability improvement (IQFinv) measured is +40% as shown in fig. 11.

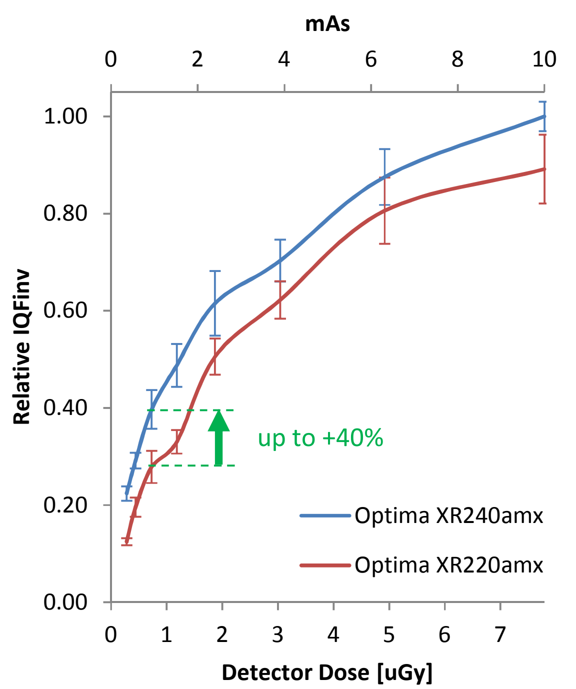
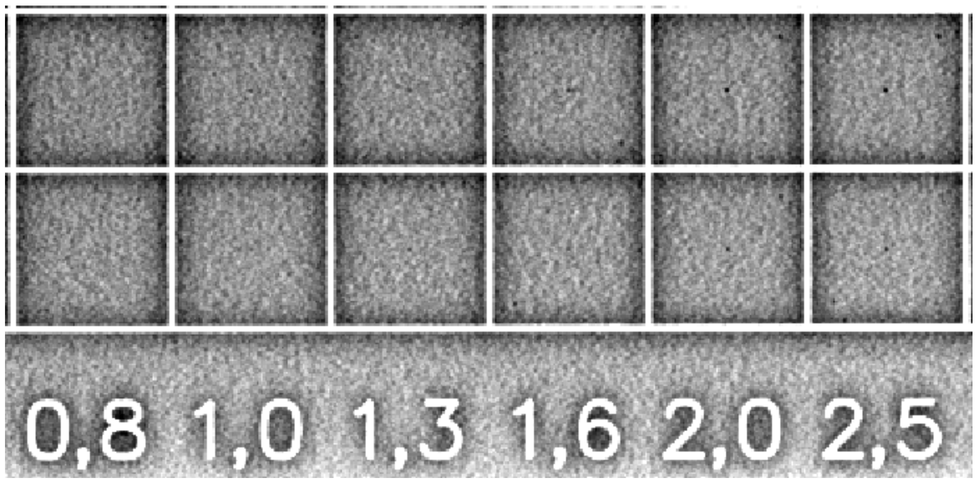
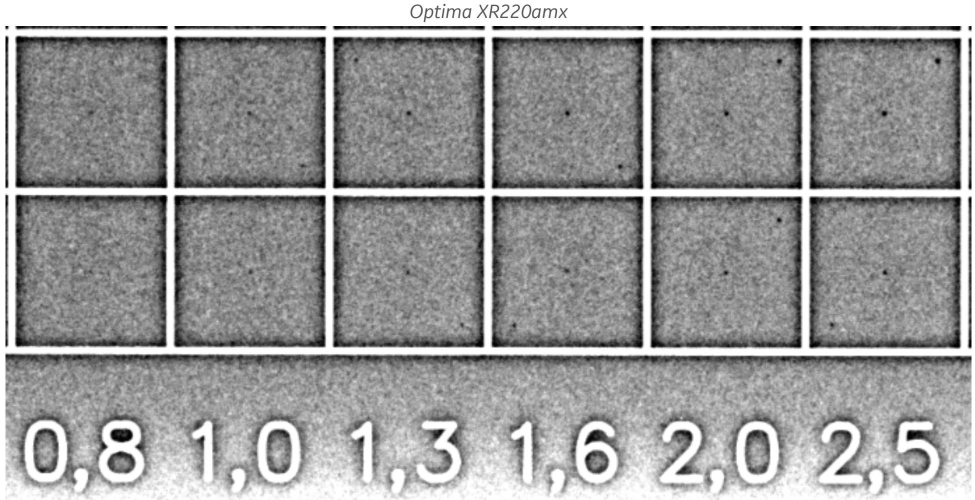


Fig. 11*: Relative IQFinv of Optima XR240amx and Optima XR220amx systems for condition 3: 20cm additional PMMA filtration, 120kV, SID 130cm*

The improvement is especially visible for small objects thanks to the resolution improvement. Fig. 12 shows the example of the 2 last lines of the CDRAD images having the smallest hole diameters, 0.4 and 0.3 mm, acquired for the two systems with condition 1 at 4mAs. To get comparable display conditions, the window center is set proportionally to pixel intensity in the cell (1.3,0.3), and the window level is set proportionally to the noise. The third image gives a schematic of the real position of the hole located in a corner for each cell, with the position the same for all images. A black dot corresponds to a physical hole in the CDRAD phantom, and more holes are visible on Optima XR240amx image.



Optima XR220amx



Optima XR240amx

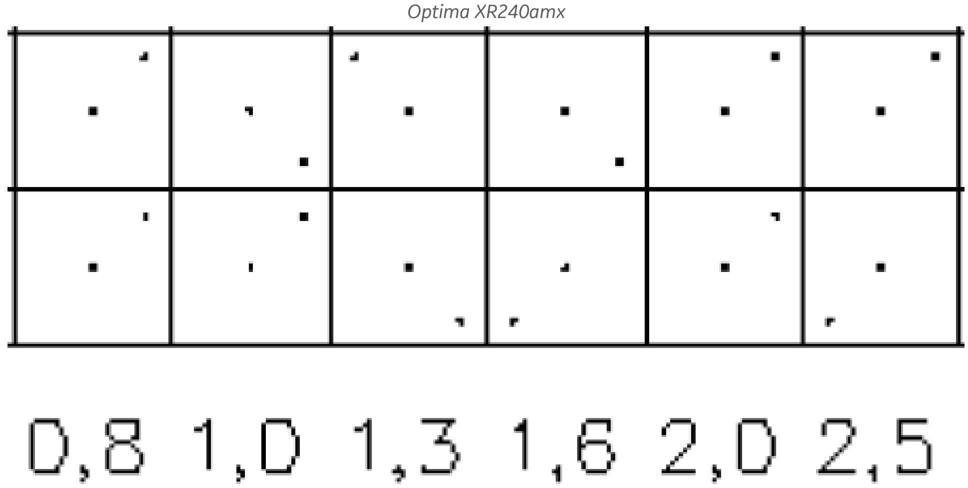


***Fig. 12**: Example of CDRAD image for condition 1 with 4mAs, holes diameter is 0.4mm on the top line and 0.3mm on the bottom line*
1st: Optima XR220amx; 2nd: Optima XR240amx
3rd: Schematic representation with real hole positions

Helix: optimized digital image processing

The Optima XR240amx with Helix image processing and FlashPad HD combine to provide exceptional resolution. The Helix digital image processing has been optimized, especially to take advantage of the additional high frequency signal contained in the raw image enhanced in the processed image. Extremities exams are a typical clinical application which will use the additional anatomical small details to visualize trabecular structure for useful clinical diagnostic. Fig. 13 shows a comparison of cadaver images of the wrist of the same patient imaged with Optima XR220amx and Optima XR240amx systems. The overall sharpness of the image is visible on the standard size image, and additional details are visible on the zoomed images. The improvements in image quality and visibility of fine structures are especially visible in extremity images and higher resolution should also be beneficial for other clinical applications.

***Fig. 13**: Cadaver wrist images of the same patient with identical exposure parameters: 60kV, 2.5mAs, SID 100cm*
Left: Optima XR220amx system, top: standard view, bottom: zoom on the radial styloid process
Right: Optima XR240amx system, top: standard view, bottom: zoom on the radial styloid process

Exams assessing the positioning of small lines are another clinical application for which resolution and small details detection are key parameters. A new custom image look for chest PA view has been developed taking advantages of the flexibility in image processing parameters as well as the high resolution provided by the detector to increase the visibility of small lines, the image can be easily reprocessed with this look in only one click with QuickEnhance. Such images can be provided in addition to the standard image to help line placement assessment without additional dose to the patient. Fig. 14 shows a real challenging clinical case acquired with an Optima XR240amx for which the same X-ray acquisition is processed with standard settings and QuickEnhance, a new custom line placement look. The nasogastric line pointed out by the arrow is not easily visible in the normal processed image and is more clearly visible with QuickEnhance on the reprocessed image with a custom line placement processing look.

Fig. 15 provides additional examples of clinical images of the one X-ray acquisition processed with two different looks without additional dose to the patient.

Fig. 14*: Challenging clinical case to assess nasogastric line placement acquired with Optima XR240amx system*
Left: Normal image processed with standard image processing parameters, bottom: zoom on the NG line
Right: Reprocessed with QuickEnhance, a custom line look designed to enhance small lines visibility taking advantages of Optima XR240amx high resolution, bottom: zoom on the NG line

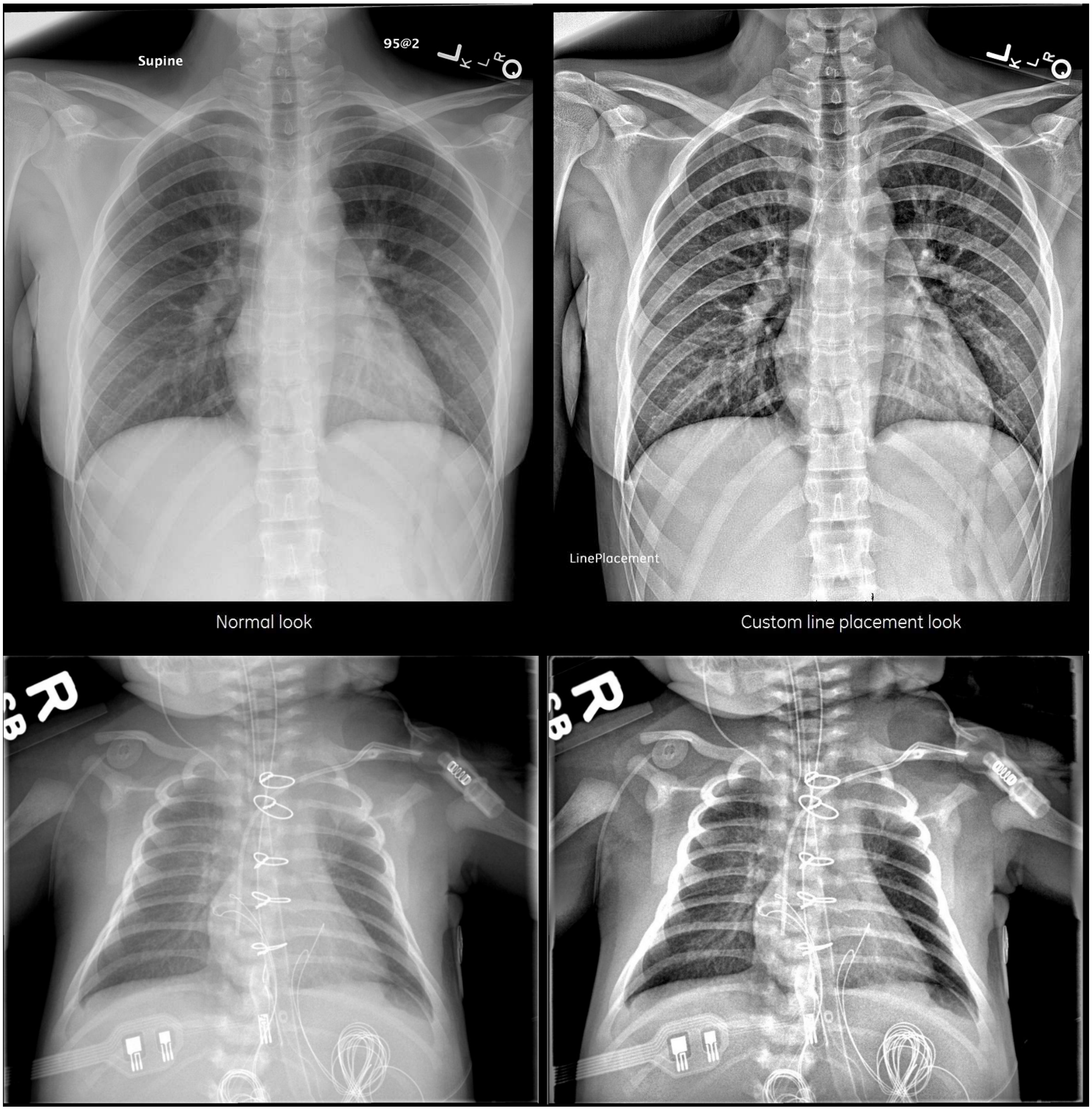


Fig. 15*: Clinical cases to assess line placement acquired with Optima XR240amx system, top: adult case, bottom: pediatric case*
Left: Normal image processed with standard image processing parameters
Right: Reprocessed with QuickEnhance, a custom line look designed to enhance small lines visibility taking advantages of Optima XR240amx high resolution

Conclusion

The Optima XR240amx, with Helix image processing and FlashPad HD 100μm wireless cassette-size digital flat panel detectors, delivers an increase of resolution by a factor of 2 compared to Optima XR220amx. Additional high frequency signal is detected and aliasing artifacts are reduced thanks to finer spatial sampling. This is achieved without noise compromise thanks to an improved pixel electronic design allowing a 10% increase of the low frequency DQE compared to Optima XR220amx. Helix digital image processing is optimized to take advantage of this additional signal and provide sharper processed images. Overall up to 40% detectability increased is measured with a Contrast Detail phantom study compared to Optima XR220amx.

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Reference

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GE Healthcare
3000 North Grandview
Waukesha, WI 53188
USA
www.gehealthcare.com

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