AGFA
RADIOLOGY
SOLUTIONS

Optimizing Patient Dose

Agfa provides technology and tools for patient X-ray dose reduction

White paper

AGFA

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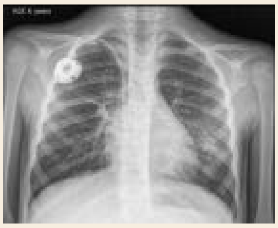
Executive summary

Agfa's digital radiography solutions are designed to deliver the optimum balance between low radiation dose and high image quality while providing the tools to monitor the patient exposures.

The Right Dose... of Expertise



Introduction

Patient safety and using the lowest possible radiation dose are a big priority at Agfa[1]. Radiography of children requires special attention since they are more sensitive to radiation and its cumulative effects. Over the course of treatment, premature infants can undergo as many as 30-40 examinations.

Lower dose means safer imaging for all patients: neonatal, pediatric and adults. Agfa makes this possible with:

- Cesium halide based Phosphor Technology
- MUSICA Image Processing with Fractional Multiscale Processing and Fractional Multiscale Denoising (FMD)
- Advanced Exposure Monitoring Tools

Projection radiography images are optimized for the visibility of clinical structures to detect pathology. In clinical practice the ALARA principle (As Low As Reasonably Achievable) must always be used to determine the proper exposure technique for a given examination. Many factors can affect the amount of exposure required for a given examination. These include examination type, patient thickness, kVp or energy level used, beam filtration, anti-scatter grid specifications, image processing algorithms and noise reduction methods used.

Another significant factor is the performance of the image capturing device, e.g. of the detector type used and, in particular, of the phosphor or scintillator used to convert the X-ray image to light. For many years Barium Fluoro Bromide (BaFBr:Eu) phosphor plates were used in conventional computed radiography (CR) systems. These image plates offer diagnostic quality at a reasonable dose.

About 10 years ago Cesium Bromide (CsBr:Eu) storage phosphors were introduced for CR. Cesium Iodide (CsI:TI) scintillators have been used for much longer in digital radiography flat panel (DR) detectors. CsBr and CsI offer improved X-Ray absorption and lead to increased detail visibility, thereby offering the opportunity to reduce patient exposure and dose. This superior performance is achieved first by the "needle crystal" structure of the Cs-halide (Br or I) phosphor and scintillator.

To determine the effect of Cesium phosphors on image quality and dose, a technical assessment and an image quality evaluation with radiologists was conducted. The goal of this evaluation was to determine how much patient exposure (and dose) could be reduced while providing the same or similar image quality when comparing conventional BaFBr plate CR system to CsBr needle plate CR system and CsI needle scintillator DR detector when processed with Agfa's MUSICA image processing.

Technology: Cesium Detector

Phosphor screens have been used for many years to convert a high energy X-ray photon to visible light photons with many types of X-ray imaging receptors. Exposing a phosphor screen with X-rays generates light[2]. Direct emission screens are used in DR systems and in conventional screen-film systems.

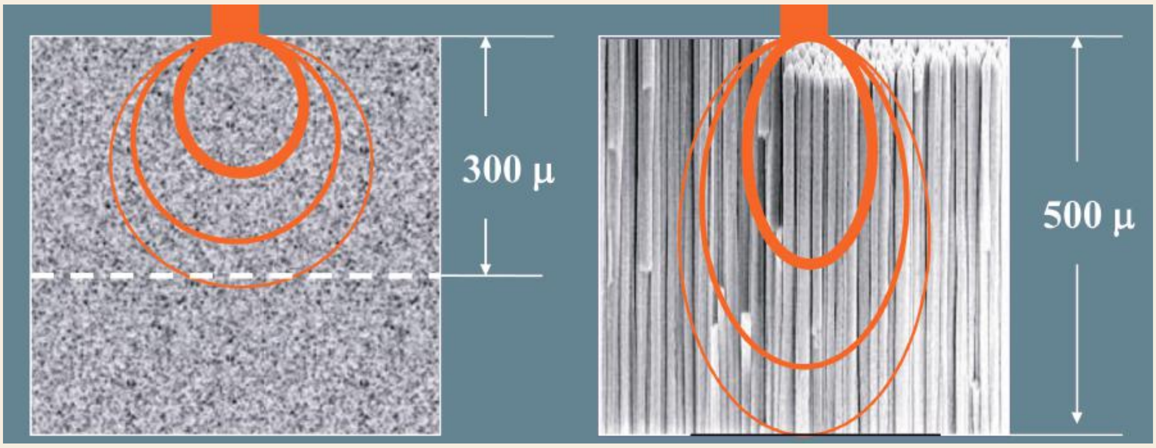
Increased X-ray absorption and sharpness: Cesium needle phosphors provide both!

- High absorption of X-ray photons in the phosphor layer is a prerequisite for good image quality.
- In needle phosphor screens, the light scattering is minimal.
- A thicker phosphor layer can be applied without jeopardizing the sharpness of the imaging system.

Storage phosphor screens with laser stimulated delayed emission are used in CR systems. The behaviour of the light in the phosphor or scintillator and the screen X-ray absorption affect the quality of the radiologic image and the required dose.

In conventional powder CR phosphor plates light photons are relatively widely and isotropically scattered in the phosphor layer, reducing the light collection efficiency of the detecting system and reducing the achievable sharpness of the imaging system. The layer thickness of the powder screens is optimized to reach the best compromise between sharpness, light yield and X-ray absorption. In practice the thickness is limited to less than 300 µm, because light from deeper layers cannot escape from the screen due to scattering in the powder layer. This limit to the thickness obviously also imposes a limit to X-ray absorption.

Fig1: Electron microscope images of phosphor layer sections on powder (left) and needle (right) phosphors. Light scattering in the powder phosphor layer will reduce the sharpness, limiting the applicable coating thickness and therefore also limiting the X-ray absorption.



High absorption of the X-ray quanta in the phosphor layer is a prerequisite for good image quality. Higher X-ray absorption is possible with the CsBr and CsI needle crystalline radiography detectors[3]. Agfa was the first to introduce this needle technology in its CR systems[4]. In a needle storage phosphor screen as in a needle scintillator, light scattering is much less than with powder phosphors and mainly in the forward direction. Hence, a thick phosphor layer can be used without jeopardizing the sharpness of the imaging system. A thick needle layer offers the same sharpness as a much thinner powder layer and, as a consequence, much higher X-ray absorption. In addition, the higher transparency of the needle phosphor screens allows photons from deeper layers to escape and to contribute to the image, which makes sensitivity higher.

Technology: Image Processing

Due to the strong focus on dose reduction in radiographic imaging, increasing numbers of radiographic images are taken at a lower dose resulting in higher noise content. Image denoising (noise suppression and removal) is a major concern in the image enhancement of radiographic images. Common denoising algorithms can make assumptions about the noise model that may not be applicable under some conditions; This can lead to loss of image quality especially in areas with low signal intensity and/or fine detail.

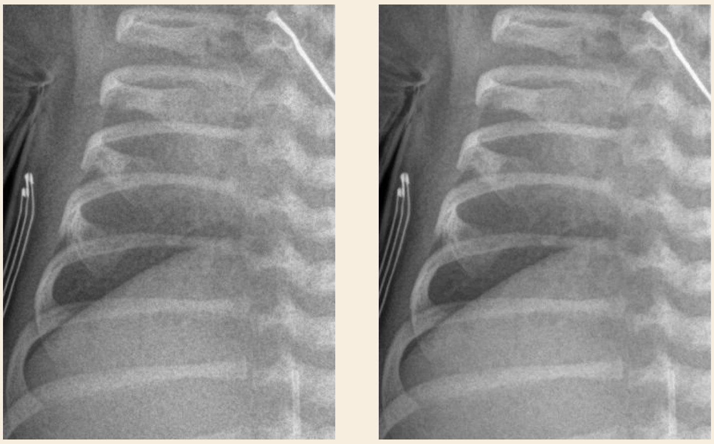
Image processing and Noise Reduction can also play a key role

- Radiographic images taken at a lower dose result in higher noise content
- Agfa's next generation of MUSICA image processing with Fractional Multiscale Denoising (FMD) can achieve active noise reduction based on selective and fractional attenuation

The next generation of Agfa's MUSICA processing[5] is based on a new mathematical multiscale framework: Fractional Multiscale Processing (FMP). With FMP, the multiscale image processing filters are further decomposed into elementary fractions which are enhanced separately.

This new mathematical technique is used to achieve active noise reduction. Fractional Multiscale Denoising (FMD) selectively attenuates elementary fractions depending on the presence and orientation of image detail. The selective attenuation is controlled by estimating the local signal-to-noise ratio. This local signal-to-noise ratio is estimated by comparing every elementary fraction to a selection of other elementary fractions in a local neighbourhood. The FMD algorithm results in much more efficient image denoising with preservation of the fine and subtle image structures.

Fig2: With FMD uniform denoising is seen in neonatal: lungs, liver and skeleton



Standard — With Denoising

Technical Image Quality Assessment

Detective quantum efficiency (DQE) is generally accepted to be the most suitable parameter for describing the imaging performance of an X-ray imaging device. It describes the ability of the imaging device to preserve the signal-to-noise ratio from the radiation scene to the resulting digital image. Since in X-ray imaging, the noise in the radiation field is related to the air kerma level, dqe values can be considered to describe the dose efficiency of the device.

Higher image quality with needle phosphor technology translates into equivalent image quality at lower exposure levels!

- DQE of Cesium based detector is more than double of that of Powder phosphor based CR detectors
- Needle phosphor detectors are used in Agfa's CR (CsBr doped with Eu) as well as in Agfa's DR systems (CsI doped with Tl)

To illustrate the higher image quality of the needle phosphors over powder phosphors the DQE of three (3) systems is illustrated for different test conditions in the following charts. DQE is measured according to the IEC62220-1: 2003[6] standard. Test conditions were RQA3 at low exposure level (e.g. pediatric, extremities) and RQA5 at medium exposure level (e.g. spinal column, shoulder, skull).

The three systems evaluated were an Agfa DX-D 35C [*1] DR detector (CsI), Agfa HD5.0 image plate (CsBr) and MD4.0R image plate (BaFBr) in DX-M CR systems. The technical evaluation of the CsBr needle CR system and the CsI needle DR detector illustrates a rather similar image quality for both systems at RQA3 and RQA5 beam qualities. Some differences can be indicated, which might be used in specific applications to optimize for image quality. Both Cesium based receptor systems produce better image quality than the BaFBr powder CR system; the DQE is more than double of that of the powder phosphor based imaging system. Needle phosphor detectors are used in CR (CsBr doped with Eu) as well as in DR systems (CsI doped with Tl) and have proven to improve the image quality compared to powder phosphor screens in clinical practice[7 8 9 10].

Fig3: DQE measured according to the IEC62220-1 standard for 3 Agfa imaging systems. DQE at RQA3 beam quality at ~0.7 µGy.

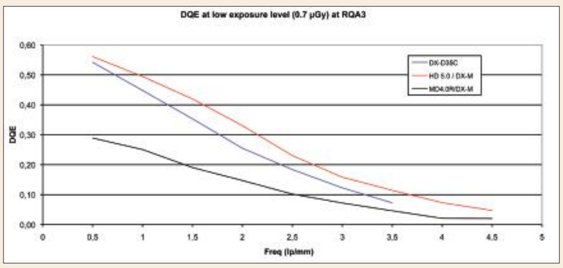
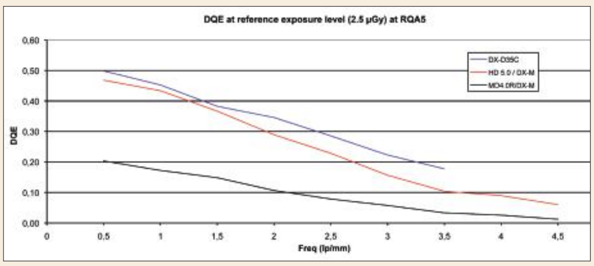


Fig4: DQE measured according to the IEC62220-1 standard for 3 Agfa imaging systems. DQE at RQA5 beam quality at ~2.5 µGy.



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Clinical Image Quality Study: Overview

To confirm that the detector systems would perform in clinical practice, as predicted by the technical assessment, five board certified radiologists evaluated abdomen, chest, hand, neonatal and skull images created with the five different types anatomical phantoms. Each phantom was exposed using each of the three detector types (CsI, CsBr and BaFBr) for a total of 15 combinations.

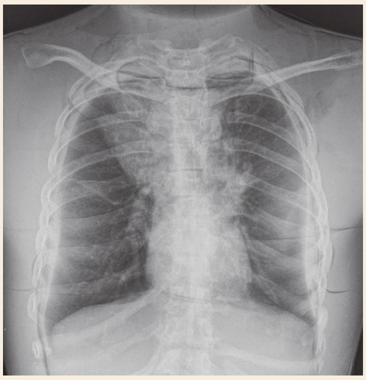
For each phantom / detector combination, 13 exposures were made with all the exposure conditions (kVp, mA, grid, distance, etc.) remaining constant except the time (ms) which varied by approximately 0.1 log exposure between each exposure. The images were grouped into 13 image pairs for each combination and displayed on a high quality diagnostic monitor. The left image was the constant or "reference" image used for the comparison set/pair; the right images were the "test" images under evaluation varying from high to low exposure.

The radiologists were asked to match the "test" images to the "reference" image. This was done by scrolling through the images until the "test" image matched the "reference" image as closely as possible as determined by the radiologist. Based on the matching set, the dose reduction was determined.

Fig5

Reference Image

CR BaFBr
ESD 191.9 uGy



Test Image with equivalent Image Quality

DR CsI
ESD 83.65 µGy

Clinical Image Quality Study: Results

Both the CsI DR detector and CsBr CR detectors with MUSICA image processing showed a substantial reduction in dose when compared to conventional BaFBr CR systems.

Up to 60% Dose Reduction is possible with Cesium based detectors and MUSICA Image Processing

- Both the CsI DR detector and CsBr CR detectors with MUSICA image processing showed a substantial reduction of between 50 to 60% in dose when compared to conventional BaFBr CR systems.

When the results were averaged across all phantoms the CsI DR (DX-D 30C) detectors produced an average dose reduction of 58% when compared to images produced with BaFBr CR (MD4.0R) plates; while the CsBr CR (HD5.0) plates produced an average dose reduction of 60%.

To confirm the performance with Neonates, the Gammex 610 Neonatal Chest phantom[11] was used. This phantom simulates a 1500 gram Neonatal patient and includes several clinical features such as a pneumothorax and simulated hyaline membrane disease. Using Cesium phosphors the Entrance Skin Dose (ESD) could be reduced from 34.4 µGy for BaFBr to 14.1 µGy for CsBr and 13.1 µGy for CsI and still achieve equivalent image quality.

Fig6: The average percentage dose reduction for CsI DR (DX-D 30C) detectors and CsBr CR (HD5.0) plates with the various phantoms.

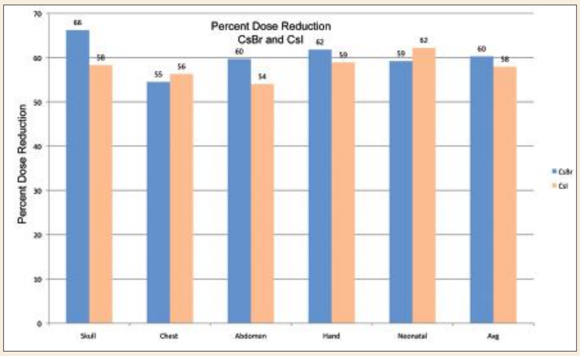
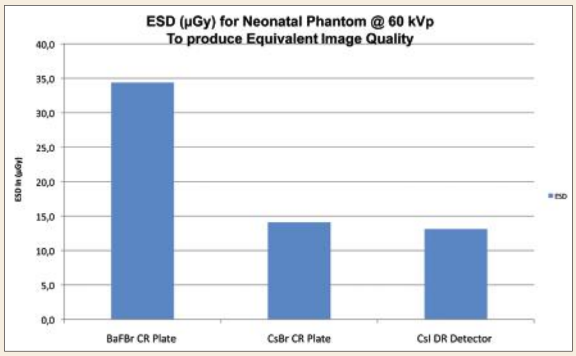


Fig7: The average Entrance Skin Dose (ESD) required for equivalent Image Quality with BaFBr CR Plates, CsBr CR (HD5.0) plates and CsI DR (DX-D 30C) detectors with a Neonatal Phantom.



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Tools

While using the best acquisition technology is an important part of any dose reduction program, proper exposure monitoring and quality assurance is equally important. If technologists and radiologists do not receive proper feedback, significant under or over exposure can occur. Agfa provides several tools to make this job easier.

To insure proper dose, ongoing exposure monitoring is key

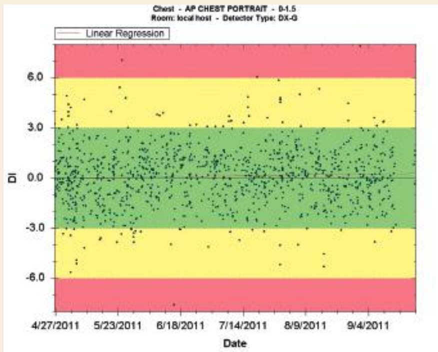
- Agfa is compliant the IEC Exposure Index standard
- Basic Dose Monitoring displays color coded exposure indicator and immediate visual feedback for technologists
- Extended Dose Monitoring provides history outlier reports, scatter plots and histograms for administrative use and quality control programs

Agfa was the first manufacturer to fully implement the IEC Exposure Index standard in 2009[12]. When this is coupled with Agfa's color-coded exposure indicator the technologist receives immediate visual feedback indicating their exposure was on target, high or low versus target and how to correct it[13].

Agfa's Extended Dose Monitoring software tools enable QC supervisors and physicists to quickly and easily monitor the exposure and dose history of an individual technologist or any CR or DR system in the department. They can also produce exposure outlier reports, scatter plots and exposure histograms to insure the proper exposure is being used for all patients and is being maintained over time[14 15].

Fig8: Basic Exposure Monitoring: colorcoded exposure indicator (green indicating "on target")

Fig9: Extended Dose Monitoring: scatter plot.



Conclusions

The ALARA principle (As Low As Reasonably Achievable) will remain the key method used to determine the proper exposure technique for a given examination. What continuously changes is the technology and the methods used to achieve the lowest reasonably acceptable dose.

Using new, more efficient technology can make a significant change in what dose is required. Substantial dose reductions of up to 60% can be achieved with Cesium halide based detectors in either CR or DR systems, combined with the Agfa MUSICA Fractional Multiscale image processing software(*).

Whenever possible, Cesium halide based detectors in combination with MUSICA should be used to minimize dose and achieve suitable image quality.

The minimum acceptable dose is also strongly influenced by the exposure variation within the department caused by equipment and technologists. If the department is well managed and maintained and the exposure variation is low, then lower average doses can be used with lower risk of under exposures which may result in repeated exposures.

The key to standardizing and monitoring exposure is the use of the IEC Exposure Index paired with an ongoing quality assurance program that includes effective exposure monitoring tools. All Agfa digital imaging products are available with the IEC Exposure Index, visual feedback and ongoing exposure monitoring tools to help minimize exposure and dose variation.

Agfa's digital radiography systems have been implemented and used worldwide since 1993. The huge installed base of more than 50,000 units clearly illustrates the confidence of customers throughout the medical communities worldwide. Our innovative and market-leading solutions can help you keep your systems and technology up-to-date and make a significant change in required dose[16].

We are committed to being your imaging solution provider for life.

(*) Testing with board certified Radiologists has determined that Cesium Bromide (CR) and Cesium Iodide (DR) Detectors when used with MUSICA processing can provide dose reductions of between 50 to 60% when compared to traditional Barium Fluoro Bromide CR systems. Contact Agfa for more details.

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16 Customer case Loma Linda, Zwanger-Pesiri radiology

About the authors

Dirk Vandenbroucke is manager of the Image Quality lab at Agfa. As a senior researcher he has contributed to the fundamental research in conventional silver halide film screen sytems and in the development of CR systems. In the past years, the focus has been on CR mammography and research on needle phosphors in various applications. He is an active member of various working groups in international standard committees (ISO, IEC). Dr. Vandenbroucke has a PhD in physics from the University of Ghent.

Bruce Apgar is based in Greenville, South Carolina (USA). As Agfa's application lead for Imaging services, he is one of the company's leading experts on dose reduction issues, especially in neonatal and pediatric environments. He represents the company, and its views, at several leading techical committees, including the American Association of Physicist in Medicine's (AAPM) tasks groups, and at the Medical Imaging and Technology Alliance (MITA). He has a B.S. in Imaging Science from Rochester Institute of Technology.

Tom Bertens is Researcher Image Processing in the R&D IT team of the Imaging division of Agfa. He develops advanced and innovative image processing and visualization software for medical image diagnosis. Mr. Bertens has a Master of Science in Electrical Engineering from the University of Leuven.

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