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Introduction

Many imaging departments are making the move from computed radiography (CR) to digital radiography (DR) as DR is becoming an increasingly attractive choice. While some facilities are in the midst of this conversion, others are still evaluating their options. In both situations, there are several factors that require attention to ensure a smooth transition from CR to DR. The technologies do have certain similarities, but often the differences between them may not be evident until after the CR has been replaced with DR in a facility. The purpose of this paper is to explain some of these differences and assist imaging providers in managing their migration to DR.

Incremental increases in productivity are critical to help healthcare organizations handle ever-larger numbers of patients while enhancing patient satisfaction, balancing staffing requirements, and successfully providing value-based care. The workflow improvements and automation possible with DR enable hospitals and imaging facilities to care for more patients without increasing staff levels.

Digital radiography also helps facilities move closer to ALARA radiation doses (ALARA = As Low As Reasonably Achievable) – which is important for all patients, but especially in pediatrics. The dose reduction potential with DR conversion likewise provides the potential for a reduction in occupational dose for imaging providers. The improved image quality possible with DR supports greater diagnostic capability and confidence, further enhancing the role of radiology as the hub of patient care.

From an investment point of view, the cost of DR continues to decrease. As departmental productivity has increased with DR, the return on investment (ROI) has also improved. Modern DR detectors can be shared between rooms, devices and operational units, allowing the healthcare enterprise to creatively maximize investments. However, to fully maximize the DR investment, technologists and facility administrators need to understand how the technology differs from CR.

This white paper discusses current DR technology and its appropriate utilization to achieve high image quality at reduced dose while increasing productivity. Topics include DR detector panel technology, DR image processing, appropriate grid selection, proper panel exposure, exposure monitoring and X-ray and electronic collimation.

Workflow Improvements: Loma Linda University Medical Center Case Study

Loma Linda University Medical Center (California, USA) upgraded from CR X-ray technology to a completely digital system with Agfa Healthcare’s Fast Forward DR upgrade program. The hospital was able to achieve measurable improvements in efficiency and patient care as a result of the upgrade, including:

- 8.16 minutes less time/exam
- Streamlined workflow and time savings
- Rapid ROI
- Capacity for 67% more exams/day; 3,285 more patients/year
- 100% FTE gain by reducing the number of technologists required from two to one on measured studies

CR to DR – Optimizing Image Quality and Dose – 3
CR and DR: similarities and differences

CR and DR both use a standard X-ray generator. With CR, the X-rays are captured using a photostimulable phosphor (PSP) plate in a cassette. After the X-ray exposure, the cassette is placed in a special scanner/reader where the latent image is retrieved pixel by pixel, and digitized. The result is an extremely accurate image that appears on the CR workstation 30 to 60 seconds after the PSP plate is scanned.

DR captures images directly, using a flat panel detector. DR detectors may be integrated into the equipment or they may be “cassette sized” (and most often wireless) to work with existing analog X-ray equipment. DR detectors completely eliminate the step of digitizing the image in a CR reader. Instead, a scintillator in the DR panel immediately converts the X-rays into visible light that is then converted into a digital signal (see figure 1 for additional details). The image appears on the DR workstation in just a few seconds.

Today, there are a broad range of DR units to fit the needs and budget of every imaging facility. Retrofit DR panels, which come in different sizes and phosphor technologies, enable “Instant DR” by upgrading analog film or CR-based X-ray systems to DR. DR rooms are available with floor mounted X-ray tubes, ceiling mounted tubes, and radiography/fluoroscopy (R/F) DR systems, while mobile DR units enable imaging to be done at the patient bedside in critical care units. Analog mobile units can also be retrofitted with DR to extend their useful life.

![FIGURE 1](image)

DR panel image capture technology

- **X-ray scintillator screen**: Contains phosphors which convert X-Rays to light
- **Photodiode layer**: Collects light and converts it into electric charges
- **Electronic control**: Triggers the TFT switches
- **Readout electronics**: Capture and amplify the electronic signals
- **TFT array**: Collects charges from photodiodes
- **TFT switching circuit**: Connects each pixel to readout device
- **Analog-to-digital conversion**
3 Image capture technologies

The choice of panel and phosphor technologies can facilitate improved image quality and a dose reduction of up to 60%, so careful selection is critical.

3.1 DR PANEL TECHNOLOGY

DR uses flat panel detectors to capture images. First, X-rays are absorbed in a phosphor screen layer, inside the flat panel detector. The X-rays are then converted into visible light. A photodiode converts this light into photo-charges that are collected via the active matrix TFT sensor of the flat panel detector, creating a signal from each pixel. These signals are amplified, digitized, processed and sent to the acquisition workstation. From the DR acquisition station, they are sent to a display, distribution and archival system (commonly referred to as a picture archive and communication system, or PACS). The digital image can be displayed on a monitor or a hardcopy image can be printed.

3.2 PHOSPHOR TECHNOLOGY

For both CR and DR, image quality is impacted by the phosphor technology used to convert the X-ray energy into light. Either powder phosphors (the ‘traditional’ technology) or needle phosphors (the high-efficiency choice) can be used. CR may use powder phosphors composed of Barium Fluoride Bromide (BaFBr) or needle phosphors composed of Cesium Bromide (CsBr). See figure 2. For DR, the scintillation layer of the detector can also be made of powder phosphor composed of Gadolinium Oxysulfide (GOS or Gadox) or needle phosphors composed of Cesium Iodide (CsI). See figure 2.

To give an example of how the selection of phosphor technology makes a difference: for a high level of X-ray absorption in the phosphor layer, a thick phosphor layer is needed. When using a powder phosphor, light scattering in the phosphor layer reduces the sharpness, limiting the image quality. The optimum compromise of resolution and X-ray absorption is reached for a layer thickness of less than ~300 µm. With a needle phosphor however, a thicker phosphor layer can be used without jeopardizing the sharpness due to the low light scattering. With needle phosphor technology, higher X-ray absorption is possible, resulting in lower dose and better image quality (i.e.) higher detective quantum efficiency or DQE*). A CsI needle phosphor in a DR system of ~500 µm thickness can have up to 50% more X-ray absorption than a powder phosphor.**

* Detective quantum efficiency (DQE) is a measure of the ability of the imaging system to preserve the signal-to-noise ratio from the radiation field to the resulting digital image, and thus of the combined effect of sharpness and noise performance. This value is generally accepted as the best measure of overall performance of imaging detectors in medical radiography.

** CR systems with CsBr needle phosphor plates can achieve similar results, when compared to BaFBr phosphor CR systems.

It is important to note that even though Cesium Iodide detectors normally reduce dose compared to powder phosphor technology, not all CsI phosphors are the same. Some manufacturers offer less expensive CsI detectors for the market segments where dose and image quality are secondary to price. These CsI detectors may use thinner phosphor layers with lower quality phosphors.

### 3.3 DR PANEL READ-OUT ELECTRONICS

During the read-out process, driver electronics, amplifiers, multiplexers and analog-to-digital convertors can introduce additional pixel noise. Recent designs of these active components have enhanced noise management properties, improving image quality at lower doses and allowing for further dose reduction.

### 3.4 PIXEL FILL FACTOR

Each pixel in a DR detector has an active sensing area (photodiode) and a switching circuit. The “fill factor” (FF) is the percentage of the pixel that makes up the active sensing area.

Lower quality sensors with larger switching circuits (TFT – thin film transistor) and lines will have lower fill factors and less active area within each pixel. DR panels with lower fill factors result in lower efficiency and thus higher image noise and lower overall image quality, compared to DR panels with smaller switching circuits and better fill factors (see figure 3).

### 3.5 PIXEL SIZE (RESOLUTION) CONSIDERATIONS

When selecting a DR panel, choosing the appropriate pixel size (sometimes referred to as ‘pixel pitch’) is important. Factors that should be considered include the type of examination being done (pediatric, adult, extremities), the dose requirements and the image quality needs.
While smaller pixel sizes have potential for higher resolution, larger pixel sizes usually have a higher fill factor and thus a higher collection efficiency. Due to the larger pixel area, more X-ray photons per pixel contribute to the pixel value, resulting in lower quantum noise. **Pixel sizes that are smaller than the resolution needed for a given examination may actually increase the noise in the image depending on the type of technology utilized. Using a larger (appropriate) pixel size that still meets the resolution requirements of the examination can reduce visible noise in the image and offers the potential to lower patient dose.**

**FIGURE 3**
At equal resolution, the smaller switching circuit area (TFT) in pixel B will result in a larger active area with better DQE and better overall image quality than pixel A
4 Image processing

4.1 IMAGE PROCESSING PERFORMANCE STUDIES

Studies have demonstrated that image processing can significantly affect perceived image quality at reduced dose. Multi-scale image processing can improve usable diagnostic information at lower doses\(^2\). (see figure 4). Fractional Multi-scale Processing (FMP) with active noise reduction, provides the potential for further reductions in dose\(^3\).

FIGURE 4

MUSICA multi-scale image processing can improve image quality and reduce dose

Image processing can improve usable diagnostic information at lower dose

Fractional Multiscale Processing (FMP)

FMP is the mathematical substructure of Agfa HealthCare’s latest MUSICA image processing software, which further decomposes image components into elementary fractions for separate processing. FMP results in a more accurate multi-scale enhancement model, a balanced participation of all filter kernel pixels in the enhancement process, and better preservation of high-resolution, low-contrast details next to high-contrast structures.

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\(^3\) Vandenbroucke D.A.N., Apgar B.K., Bertens T. Optimizing Patient Dose. Agfa HealthCare White Paper Dec 2014
4.2 WHAT TO LOOK FOR IN IMAGE PROCESSING SOFTWARE

Image processing software should provide consistent performance, for all body types and patient ages (neonatal, pediatric, adult, bariatric, etc.), over a wide range of exposure factors. It should not create artifacts, should be tolerant of over and underexposure, and should especially be low-dose friendly.

The software should increase productivity: reducing, not increasing, work for radiology staff. This means little to no post-processing, automatic window/level adjustments, automatic electronic masking and excellent area of interest (AOI) accuracy. Configuration and set-up should be easy: the software should work well out of the box with little or no ongoing maintenance, include simple and understandable adjustment settings, and avoid complex parameter adjustments that require set-up and maintenance by imaging specialists.

5 Anti-scatter grids

5.1 GRID SELECTION AND SPECIFICATIONS

Grid performance factors can also have a significant impact on the digital image. Some of the most important factors include:

- Grid ratio – impacts image quality
- Bucky factor, or the amount by which the exposure must be increased or decreased when using a grid – impacts dose
- Reciprocating (moving) versus stationary – impacts visibility of gridlines (it is important that the gridlines are not visible)
- Line rate (frequency) (in lines/cm or inch) – impacts artifact minimization
- Focal distance – impacts artifact minimization and grid cut off
- Grid positioning, including angle and distance – impacts image quality
- Grid line direction – impacts positioning flexibility

**FIGURE 5**  
Example of anti-scatter grid label displaying specifications
5.2 GRID LINE SUPPRESSION SOFTWARE

Most newer DR systems use stationary grids instead of reciprocating grids. To remove grid lines from the final image, grid line suppression software (GLS) is used. Grid line suppression software automatically identifies repeating patterns caused by the grid-panel interference, and removes them. The result is improved viewing conditions and workflow options.

To ensure the grid line suppression software works correctly, it is important to follow the manufacturer’s recommendations when selecting a grid. The pixel pitch of the panel, the grid type and lines per inch can influence the appearance of grid lines. Improper grid selection may result in image artifacts caused by the interference between the DR panel and grid (see images, figure 6). The chart below (figure 7) shows the results of an image quality evaluation using Agfa HealthCare’s GLS grid line suppression software in combination with different DR and CR plates and grid specifications. The best results are indicated in green font.

**FIGURE 6**

Grid line artifacts (aliasing or moiré patterns)  
Grid line suppression software removes artifacts
### 5.3 GRID ALIGNMENT

Incorrect grid alignment can lead to poor image quality. **This is a common problem in portable/bedside imaging and can be the source of many image quality complaints.** Correct grid alignment requires the angle of the tube/collimator to be the same as that of the grid/panel. The tube/collimator should be parallel to the plane of the anti-scatter grid and the appropriate distance used for the recommended grid type. Improper alignment will result in increased scatter, grid cut-off and overall poor image quality.
5.4 FOCUSED GRIDS

Some grids are labelled as ‘multi-focus’, providing a focal range rather than a single focal distance. This focal range is always a compromise; the actual focus falls somewhere within the range. At the extremes of the range, the image will experience grid cut-off and grid lines may be visible at the edges of the image (see figure 8). Many DR systems offer multiple grid options depending on the distance required for the examination (Figure 11).

For the best results, use the correct SID and anti-scatter grid with the right focal distance for the exam.

For example: 72 inches for chest imaging, 40 inches for abdomen, spine, shoulders etc.
5.5 GRID LINE ORIENTATION

- Most stationary grids used in portable/mobile radiography are the same size as the DR panel being used.

- Grid lines are often oriented along the long dimension, but may be oriented along the short dimension (aka "decubitus" grids). Decubitus grids may be preferable for chest images done with the detector in the landscape orientation.

- Grids in tables and upright buckys are usually 17-20" square grids.

5.6 NON-GRID SCATTER SUPPRESSION SOFTWARE

Although the use of grids is optimal from a physics standpoint, as previously stated, when using a grid several items must be monitored to ensure proper image quality.

- Grids need to be properly centered and positioned to improve image quality. If they are not, they can actually reduce image quality and this can easily occur during mobile radiography.

- Grids can become damaged over time.

- Grids may create artifacts in the images (known as aliasing or moiré patterns).

- Grids typically require a higher radiation dose.

- Grids may require longer exposure times.

- Grids add weight to the detector and increase muscle strain for technologists, especially during bedside/portable radiography.

Because of the time and effort required, in certain cases it may be preferable to avoid using grids, for example in bedside chest imaging.
Recently "non-grid" scatter suppression software has become available which uses advanced image processing to reduce (not eliminate) the need for a grid. Since scatter radiation is primarily visible in the low frequency component of an image, scatter suppression software extracts the low frequency scatter information from the image, while enhancing the medium to high frequencies in the image. This results in enhancement of the relevant clinical information while reducing the visualization of scatter. For example, scatter suppression software can improve lung field detail without the use of an anti-scatter grid.

Scatter suppression software may also be used with a grid in some cases, to provide the best overall result, for example with bariatric patients. In these cases, high amounts of scatter can be present in the image even when using a grid, depending on the patient size. Thus, scatter suppression software can improve image quality.

When using scatter suppression software, each department should establish guidelines for the appropriate use (or not) of grids, particularly with mobile or portable examinations. The patient type (pediatric, normal or bariatric) should be considered, as well as the examination criteria (such as ruling out foreign bodies or providing more prominent visualization of catheters and fine needles) when determining what type of grid and image processing should be used.

While a grid will increase image quality, grid techniques require proper positioning and a higher overall dose (up to 50% increase), compared to non-grid exposures.
In summary, image processing software may be able to eliminate the need for a grid with DR depending on:

- The application: mobile or in-room
- The patient size/type: pediatric, normal, obese, bariatric, etc.
- The workflow requirements: grid + panel weight and correct alignment, SID
- The examination criteria: image quality, dose

Generally, "non-grid" image processing should be seen as an option in the DR "toolbox". It should be considered and used when appropriate in order to improve image quality and workflow, and reduce dose.

6 Exposure and dose

6.1 DYNAMIC RANGE

DR images can offer higher contrast and sharpness. DR panels also normally require less exposure (dose) to achieve equal or better image quality, especially with cesium-based detectors. However, there is significantly less exposure latitude with DR because of the smaller dynamic range compared to CR.

The dynamic range is the ratio between the highest exposure level without saturation artifacts and the lowest exposure level detectable above the intrinsic noise level. CR typically has a dynamic range of approximately 10,000:1. The dynamic range of DR systems is about 200:1 for older systems, and up to 1500:1 for newer, 16-bit systems. Traditional film screen systems have a dynamic range of about 25:1. Thus, DR systems offer a larger dynamic range than film screen systems, but a much smaller range than CR systems.

The exposure latitude of a system indicates to what degree the mAs can be changed from the ideal exposure for a single patient, and still achieve acceptable image quality. The exposure latitude depends on the type of system used (film, CR or DR), the dynamic range of that system, and the type of body part being imaged. The acceptable exposure latitude is often expressed as the change in milli-amperage seconds or mAs, which corresponds to a change in dose.

The exposure latitude of a CR system is much greater than that of a DR or film screen system. For example, for a lateral skull examination, CR typically has an acceptable exposure range of -4X mAs to +16X mAs (or more). DR has an acceptable exposure range of about ±4X mAs from the ideal exposure. A DR exposure variation greater than +4X mAs can result in image saturation, and the data is not usually recoverable. Therefore, with DR systems, great attention must be paid to exposure accuracy in order to prevent image saturation and overexposure (see figure 14).
6.2 THE INTERNATIONAL EXPOSURE INDEX STANDARD

In 2008 the International Electrotechnical Commission (IEC) published the IEC 62494-1 standard, “Exposure index of digital X-ray imaging systems”. It outlines a methodology for monitoring exposure consistency within an exam type, and provides a standard way to measure the exposure to a digital detector.

The index consists of three values: Exposure Index (EI), Target Exposure Index (TEI) and Deviation Index (DI).

- The Exposure Index (EI) is related to the exposure reaching the receptor. If the mAs is doubled, the exposure index is doubled; if the mAs is halved, the EI is also halved. The relationship is therefore linear under all conditions. The EI is a relative exposure measurement, within each exam type. It is not intended (and should not be used) as a calibrated dose meter or a measurement of dose. To confirm the performance of the exposure index, a flat field exposure can be made with a calibrated (RQA-5) beam. The IEC standard indicates that the exposure index results should fall within ± 20% under these conditions.

- The Target Exposure Index (TEI) is the reference (e.g. ideal) exposure index for a particular examination view. Various exams will have different TEI values, depending on the detector type and image quality needs. For example, the TEI for extremities may be 900; for chest, the TEI may be 250; an abdominal TEI may be 350, etc. The TEI is used to calculate the Deviation Index (DI).

The goal when selecting the TEI should be to achieve acceptable image quality at the lowest possible dose (ALARA). Lower TEI values will require less dose, but will reduce image quality. Once a TEI value is selected, individual EI values may fall outside of these ranges due to normal variations in exposure.

The TEI can be set by an applications specialist with input and recommendations from the hospital, or can be determined based on the average of a number of exposures. The TEI should never be changed based on a single image exposure, but rather on statistics from multiple exposures. 

**Check with your manufacturer for initial TEI recommendations.**

*FIGURE 15*

Agfa HealthCare’s suggested Target Exposure Index (TEI) starting points for various examinations and Agfa HealthCare DR panel types (CsI or GOS). The final TEI values used should be determined by the imaging requirements of the radiologists, and normally should be somewhere between the minimum and maximum values shown.

<table>
<thead>
<tr>
<th>Examination</th>
<th>General work (chest, abdomen, etc)</th>
<th>Shoulders, spines*</th>
<th>Extremities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starting point</td>
<td>Min.</td>
<td>Max.</td>
</tr>
<tr>
<td>DR-CsI (needle)</td>
<td>350</td>
<td>150</td>
<td>500</td>
</tr>
<tr>
<td>DR-GOS (powder)</td>
<td>700</td>
<td>300</td>
<td>1000</td>
</tr>
</tbody>
</table>

*If the image quality is acceptable, lower TEI values (100 to 150) may be used on repeated scoliosis studies to minimize dose.

- The Deviation Index (DI) expresses how far a single exposure is from the TEI (the reference). It thus provides a relative indication of under or overexposure. The DI is equal to 10x the logarithm of the ratio of EI for a given exam view to the TEI for the exam view. One deviation unit equals ~25% (+1 or -1) over or underexposure (similar to an automatic exposure control (AEC)). Three deviation units equals 2x or ½x of the target exposure (+3 or -3). While in a perfect world, DI would be 0, this is of course rarely the case. Studies have shown that when the TEI is properly selected, 90 - 95% of the deviation index values fall within -3 to +3 deviation units from the target for manual exposures and -2 to +2 deviation units for AEC exposures. On the Agfa HealthCare DR acquisition station, dose monitoring software must be active to display DI and TEI values and the associated color-coded graphic on the image.

*FIGURE 16*

Exposure Index with Deviation Index display

**Exposure Monitoring Software**

Exposure Monitoring Software includes a color-coded exposure (dose) bar that indicates how far the image EI is from the TEI. the dose bar is green when on/near the target EI, turns yellow when over/underexposed by a factor of 2 and red when over/underexposed by a factor of 4 (see graphic display). While the bar gives a relative indication of the exposure to the plate, and is a good measure of the variation of the exposure to the plate within a given exam type, it is not an absolute measurement of patient dose or absorbed dose.
6.3 DICOM MAPPING OF EI, TEI, DI AND DAP

The EI, TEI, DI and DAP values can be displayed on the PACS workstation using the appropriate DICOM tags. The DICOM committee has defined the following tags for EI, TEI, DI and DAP (Dose Area Product):

- EI: (0018,1411)
- TEI: (0018,1412)
- DI: (0018,1413)
- DAP: (0018,115E)

6.4 COLLIMATION

X-ray collimation reduces the exposed area, lowering patient dose and reducing the influence of X-ray scattering. Proper X-ray collimation significantly impacts dose and image quality with DR. When X-ray collimation is done correctly, the area of interest should be detected automatically, and minimal manual cropping should be necessary.

When the X-ray collimated area is larger than the area of interest, the technologist may wish to electronically crop or mask the image manually after exposure. However, many facilities have policies in place that minimize or eliminate this practice, because when cropping is done the radiologist may be unaware of the actual patient exposure, both in terms of quantity and anatomy. Therefore, manual cropping or masking after exposure should be the exception not the rule.

6.5 DR REPEAT RATES

Because of the ease of use, repeat rates with DR are actually increasing in some cases. Repeats are frequently taken to modify positioning because the image is available quickly and the patient is still positioned on a detector. While this may offer advantages for the diagnostic and technical quality of images, it should be kept in mind that this also results in increased radiation dose for the patient. Overall, reduced repeats are a potential advantage of digital radiography, and care must be taken not to negate these benefits unnecessarily.

Conclusions

To summarize,

1. Moving from CR to DR brings significant improvements in efficiency and patient care
2. Panel technology and phosphor type can reduce dose by 50-60% and influence image quality, so careful selection is critical.
3. Proper image processing can significantly improve image quality and reduce dose and repeated images as well. Image processing software should provide consistent performance for all patient profiles, over a wide range of exposure factors.
4. Anti-scatter grids and their correct positioning can improve image quality. The required specifications for grids used for DR may be different than for CR. Therefore, check with your manufacturer. Depending on the examination, it may be preferable to avoid using anti-scatter grids. “Non-grid” scatter suppression software can reduce the need for anti-scatter grids in many cases.

5. Proper technique selection is more important than ever. The dynamic range of DR is lower than that of CR, so DR images can be saturated and unrecoverable in some cases. DR systems should fully conform to the IEC Exposure Index standard to insure proper monitoring and control of exposure.

6. X-ray collimation influences scatter, image processing and overall image quality. Improper electronic collimation, cropping or masking to correct for poor X-ray collimation reduces image quality, increases patient dose, and may be against the healthcare facility policy. Certainly, manual masking/cropping is not a best practice!

8 Making the move from CR to DR: further reading

ASRT white paper: Best Practices in Digital Radiography

ASRT article: Radiation Safety Compliance
https://media.asrt.org/pdf/publications/RADT_Vol87_No5_CT.pdf (see page 511 and further)

Agfa HealthCare white paper: Optimizing Patient Dose

Agfa HealthCare white paper: Non-grid Bedside Chest Imaging

About the authors:

Bruce Apgar is based in Greenville, South Carolina (USA). As Agfa HealthCare’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 technical committees, including the task groups of the American Association of Physicists in Medicine (AAPM), and at the Medical Imaging and Technology Alliance (MITA). He has a B.S. in Imaging Science from Rochester Institute of Technology.

George Curley RT(R) has been with Agfa HealthCare for 25 years. He is currently Senior Sales Marketing Manager of Digital Imaging Products for North America. He is a radiographer and former radiology manager with extensive experience in digital imaging clinically and commercially.

Dirk Vandenbroucke is an R&D scientist investigating innovative technologies for Agfa HealthCare’s medical imaging systems. As a senior researcher, he has contributed to the fundamental research in conventional silver halide film screen systems and in the development of CR and DR systems. 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.
Agfa HealthCare, present in one hospital out of two, is a leading provider of eHealth & Digital Imaging solutions. Care organizations in over 100 countries rely on Agfa HealthCare to optimize their efficiency and improve patient care.