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## Analog and digital systems of imaging in roentgenodiagnosics

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### Summary

In the recent years, we have been witnessing a very dynamic development of diagnostic methods of imaging. In contemporary radiology, the carrier of the diagnostic information is the image, obtained as a result of an X-ray beam transmitted through the patient's body, with modulation of intensity, and processing of data collected by the detector. Depending on the diagnostic method used, signals can be detected with analog (x-ray film) or digital systems (CR, DR and DDR). Each of these methods of image acquisition, due to its own technological solutions, determines a different quality of imaging (diagnostic data). The introduction of digital image receptors, instead of conventional SF systems, increased the patient dose, as a result of a gradually increasing exposure. This followed from the fact that in digital systems, the increased radiation dose reduces image noise and improves image quality, and that is owing to the data capacity of these systems (impossible in SF systems with a limited data capacity of the image detector). The availability of the multitude of imaging systems, each characterized by disparate qualitative and quantitative parameters, implies the problem of evaluation and enforcement of a proper efficiency from manufacturers of these systems.

At the same time, there is a legal problem present in our country, i.e. the lack of laws and regulations regarding standards of the scope of quality control (parameters) and measurement methodology for the systems of digital image acquisition. In the European countries, the scope and standards of control are regulated by the manufacturers and European Guidelines, whereas in the United States, AAPM Reports have been introduced, that specifically describe methods of tests performance, their frequency, as well as target values and limits. This paper is a review of both, the scope of quality control parameters of image detectors in analog and digital systems of imaging, and the measurement methodology. The parameters determining the image quality are as follows: detection efficiency, dynamic range, spatial sampling, contrast resolution, spatial resolution, noise, and quantitative detection efficiency. Validation of the measurement methods, establishing standards of radiographic techniques for the performed examinations, and creating a uniform system of supervision, appears to be the only way to ensure an effective control of imaging systems and to eliminate an increasing exposure.

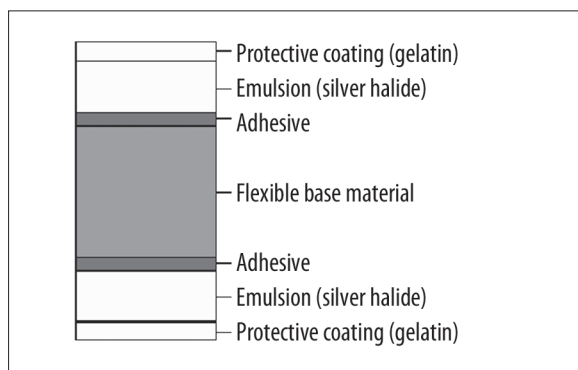
**Key words:** SF Radiography • CR Radiography • Digital Radiography

**PDF file:** <http://www.polradiol.com/fulltxt.php?ICID=878520>

### Background

In the modern diagnostic radiology, the carrier of the diagnostic information is the image, obtained as a result of an X-ray beam transmitted through the patient's body,

with modulation of intensity, and processing of data collected by the detector. Depending on the diagnostic method used, signals can be detected with analog (x-ray film) or digital systems (CR, DR and DDR). Each of these methods of image acquisition, due to its own technological solutions,



**Figure 1.** Cross-sectional diagram of the X-ray film.

determines a different quality of imaging (diagnostic data). Therefore, quality control procedures and their scope, as well as the tested parameters and evaluation of the detection efficiency vary between these two diagnostic systems. At the same time, there is a legal problem present in our country, i.e. the lack of laws and regulations regarding standards of the scope of quality control (parameters) and measurement methodology for the systems of digital image acquisition.

### Imaging Systems in Diagnostic Radiology

Imaging in diagnostic radiology is based on three technological solutions of diagnostic data acquisition:

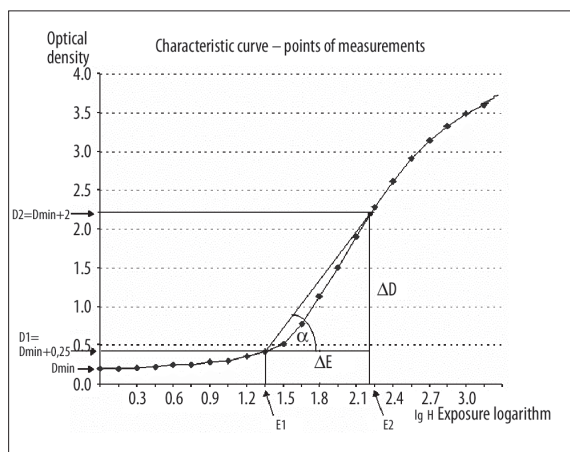
- Analog systems: cassette with an intensifying screen, x-ray film, negatoscope;
- Computed radiography: cassettes with imaging plates, CR reader, control station with monitors for description;
- Direct and indirect digital systems (DR and DDR) - plates of amorphous silicon coated with a layer of scintillation material, such as cesium iodide (CSI) used in image intensifiers or TFT matrix (electrically controlled switches, thin-film counterparts of MOSFET-type transistors), control station with monitors for description.

Each of the above mentioned systems and technological solutions is characterized by properties influencing image parameters, i.e. improving their quality, as well as causing the loss or deterioration of the diagnostic information.

#### Analog systems

Analog image detector of an X-ray unit consists of three components: X-ray film, intensifying screen and light-proof housing (cassette). An ancillary part of this imaging system is the developing device along with reagents for photochemical processing of X-ray films (developer, fixing agent, water) and the dryer

X-ray film is made of a thin, transparent, flexible polyester film (base material of X-ray film) and a thin layer of a photographic emulsion (Figure 1). The emulsion is coated with protective polymer layers and with a dulling agent. The photosensitive elements are silver halide microcrystals. Quanta of X-rays or visible light radiation energy emitted by the intensifying screens transfer their energy, as soon as they reach the silver halide crystals. If the energy is sufficient, crystal electron can be transferred from the



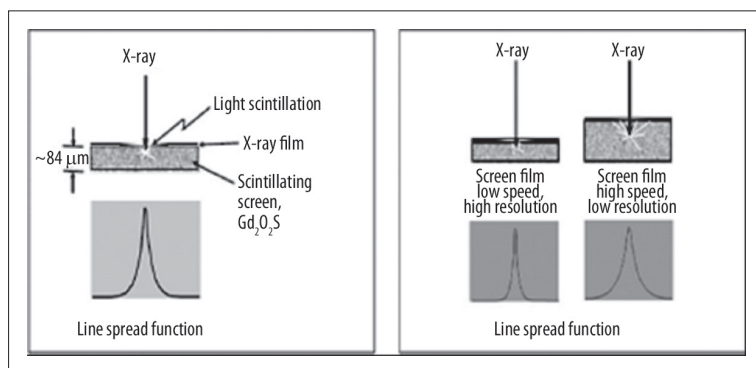
**Figure 2.** Definite points on the characteristic curve.

valence band to the conduction band, where it can move freely throughout the crystal. The electron moves until it reaches the place of crystal structure distortion, where it is 'trapped'. The presence of the 'trapped' electron with a negative electric charge causes the attraction of positively charged silver ions, which further leads to origin of a metallic silver atom in that particular place. This place becomes a part of a latent image. As a result of this process, latent image sites may occur on the crystal, large enough (several to over a dozen of atoms of metallic silver) for the developer to initiate the process of reduction of the whole crystal to metallic silver. The amount of the developed metallic silver determines the level of blackening (optical density), creating a real image on the film. "Revealing" of the image on an X-ray film proceeds in the course of photochemical processing.

X-ray film has a certain performance characteristics, the parameters of which should be taken into account when setting the exposure conditions and the proper degree of film utilization. Sensitometric properties of light-sensitive materials are determined by the characteristic curve (Figure 2), i.e. the graph of function of the optical density over the logarithm of exposure, where the exposure ( $E$  or  $H$ ) is the product of illuminance ( $I$ ) and exposure time ( $t$ ), and the optical density is the logarithm of the quotient of incident light intensity to light intensity transmitted through the exposed X-ray film. Photosensitive material does not react in areas of low exposure, and the obtained optical density results from optical density of a base material coated with photosensitive layers ( $D_p$ ), and from optical density of fog ( $D_0$ ), which added all together, constitutes the minimum optical density ( $D_{min}$ ). With a certain value of exposure, the value of optical density starts increasing slowly and converts into the linear dependency with a specific angle of inclination.

Increasing exposure reduces the increase of density and the characteristic curve reaches plateau, parallel to the axis of exposure logarithm, at a constant density – the maximum density ( $D_{max}$ ), when the level of the reached exposure resulted in the development of all crystals contained in the layer.

Sensitivity index and contrast index are the main sensitometric measures derived from characteristic curve.



**Figure 3.** Principle of operation of the intensifying screen - impact on the sensitivity and resolution of the imaging system. (by Andrew P. Smith, Fundamental Digital Mammography, Physics, Technology and Practical Considerations.)

### Sensitivity index

Sensitivity of the photographic material is defined as the smallest amount of light required to produce a certain optical density. It is equal to the value of logarithm of exposure needed to obtain optical density defined as  $D_{cr} = D_{min} + 1.0$ , which determines a corresponding value of the logarithm of exposure.

### Contrast index

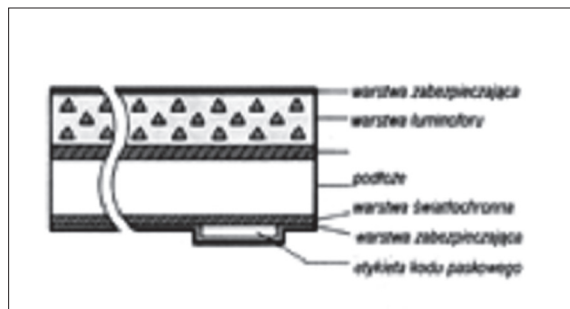
Contrast is defined as a measure of differences in optical density in the image and it can be calculated from the inclination of the rectilinear part of the characteristic curve. It is defined as the gradient at a point (e.g., contrast index  $\alpha$ , being a slope of a tangent to a characteristic curve at inflection point near the middle of the rectilinear part) or as a mean gradient, defined as the slope of the segment joining two definite points of optical density  $D_1 = D_{min} + 0.25$  and  $D_2 = D_{min} + 2.00$  (Figure 2).

The main imaging parameters are the optical density, contrast and resolution, where:

1. Optical density means the blackening in the image, and is defined as the value of the decimal logarithm of the inverse transmission coefficient. This coefficient can be brought down to a ratio of the intensity of the light transmitted through the particular point on the image, to the intensity of the incident light at that point:

$$D = \log (1/T) = \log (I \text{ incident}/I \text{ transmitted})$$

2. Contrast is a measure of differences in blackening of the selected image fields, corresponding to the differences in density and thickness of tissues shown in the image. Image contrast depends on the quality of radiation, the structure of an examined tissue or organ, film sensitivity and type of intensifying screen, as well as the quantity of the scattered radiation and the degree of film fogging.
3. Image resolution is determined by the number of line pairs per millimeter (lp / mm), which can be visualized and identified as separate structures. Resolution defines the smallest size of an object possible to visualize, and thus determines the smallest distinguishable distance between two objects (Figure 3).



**Figure 4.** Structure of an imaging plate.

X-ray film is a detector of finite data capacity. Thus, it is very important to optimize the process of image creation, starting with the proper setting of the unit (exposure control), through photochemical processing (sensitivity of the system, artifacts in the image, noise level), the darkroom lighting conditions, right selection of imaging parameters of the whole set (intensifying screens within the range of the emitted light wavelength, corresponding to the parameters of x-ray films). Properly set elements of diagnostic data creation translate into the creation of the most favorable conditions for achieving an image of a proper quality.

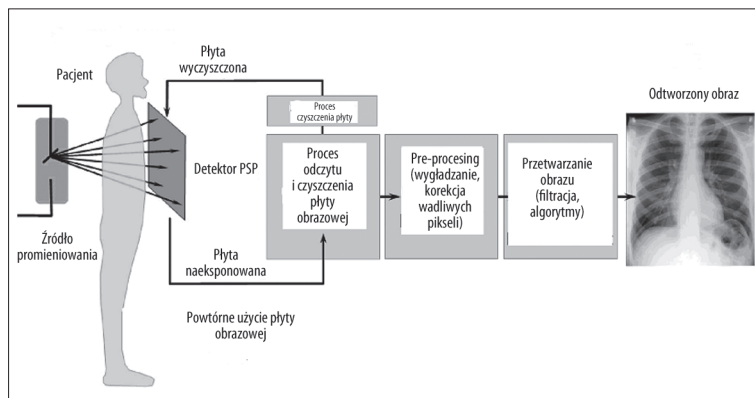
In analog systems, the qualitative and diagnostic assessment of an image is performed using negatoscopes in reading rooms which should strictly comply with parameters defining the appropriate lighting conditions (no more than 50 lux) and conditions of luminance of the emitted light ( $\text{cd}/\text{m}^2$ ).

### CR systems

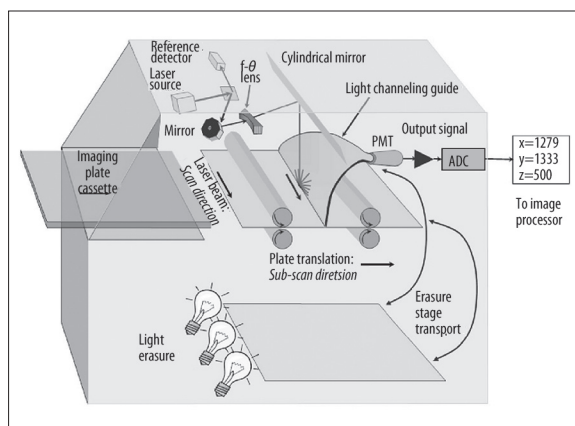
Phosphor imaging plate constitutes an imaging detector in digitized computed radiography (CR). An essential component of its structure is a layer of luminophore (PSP – Photostimulable phosphor imaging system) (Figure 4).

Imaging plate is placed in a cassette similar to the one used for analog radiography; geometry and imaging technique are similar as well (Figure 5).

Patient, source of radiation, erased plate, PSP detector, exposed plate, imaging plate reutilization, plate erasing process, process of imaging plate readout and erasing, pre-processing (smoothing, defective (bad) pixels repair), processing of the image (filtration, algorithms), reconstructed image



**Figure 5.** Scheme of image processing and recording on imaging plate.

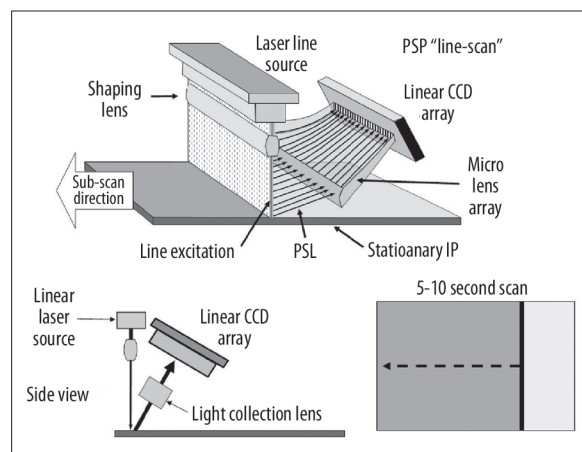


**Figure 6.** The process of image readout from an imaging plate – point-scan system.

In the systems basing on phosphorous imaging plates (CR), X-ray radiation quanta are absorbed by a phosphor layer of the imaging plate (IP). Unlike the conventional intensifying screens, the energy of X-ray radiation deposited in the material of imaging plates is stored in a portion of energy, located in metastable regions called F-centers. During x-ray beam exposure, the latent image is formed in phosphorus by accumulation of energy in these centers and revealed by the reader scanning the imaging plates. By scanning the IP with a narrow laser beam and processing the data, a diagnostic image is generated out of the latent form. In case of point-scan readout in the scanner (Figure 6.), the imaging plate is moved in one direction, while the concentrated laser beam moves perpendicularly to that direction, from one side of the imaging plate to the opposite one.

The entire surface of the plate is scanned by the laser beam and the light generated in the process of photostimulation and emitted by each point of the imaging plate, is collected by an optical fiber. Time of plate readout depends on the size of the detector and speed of the reader (average scanning takes about 60–70 s). In modern technology readers, a linear laser source is used (Figure 7), which increases the speed of data readout (average scanning time is about 5–10 s). In such reading scanners, the linear laser beam scans the stationary imaging plate.

Atoms returning to equilibrium (ground state) generate the emission of photons from the spectrum of the visible light wavelength, and this phenomenon is recorded by a

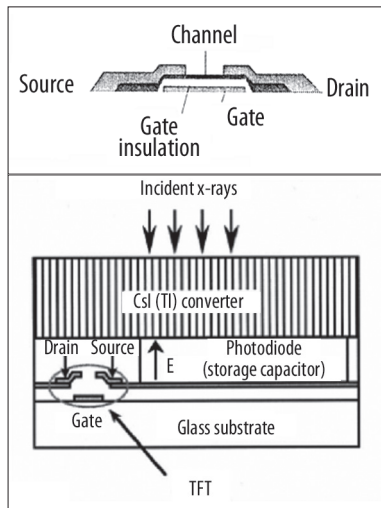


**Figure 7.** The process of reading the image from the imaging plate – line-scan system. Schematic diagram of a line-scan PSP system. (According to the AAPM Report No. 93).

photomultiplier. The recorded amount of light generated by photostimulation (PMT) stays in adequate proportion to the number of F-centers, and thus also to the amount of x-ray radiation absorbed in that point. Photomultiplier converts the light image into the analog electric signal, which, on the output, is converted into a digital signal by an analog-digital converter. Before digitization, the PMT signal is intensified, usually in a non-linear manner. As a next step, 'raw' signal values are processed in segmentation, rescaling and filtering procedures, using mathematical algorithms.

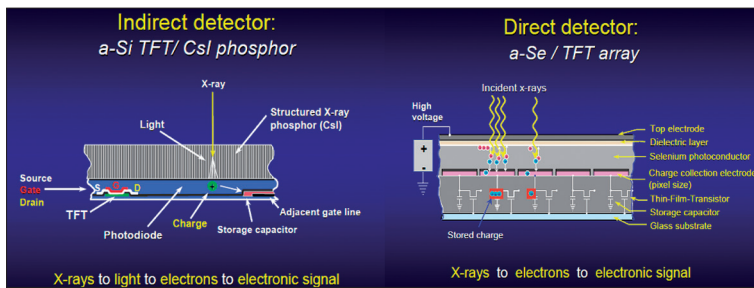
After reading is completed, the imaging plate is exposed to a visible light emitted by the erasing lamp that 'deletes' the X-ray image and makes the imaging plate ready for reuse.

In order to optimize the effectiveness of imaging plate utilization within a wide range of exposure, the digitized systems provide the pre-reading procedure, which allows for testing the sensitivity of the signal reading. Initially, a weak laser beam is used for reading a "raw" image data. Appropriate reading, sensitivity and exposure conditions are determined basing on analyses of the data obtained in pre-reading procedure. The proper reading follows the above mentioned procedure. This method enables normalization of the range of luminescence, in which the x-ray image appears, in order to allow the conversion to digital signals, irrespectively of the object being tested and the X-ray radiation dose.



**Figure 8.** Thin-film transistor structure (according to MEDTECH).

In CR systems of digital radiography the phenomenon of fading (loss of the recorded signal) occurs, which is disadvantageous for image acquisition. Hence, the time frame between the exposure of the imaging plate and the reading process is crucial. An average image recorder loses about



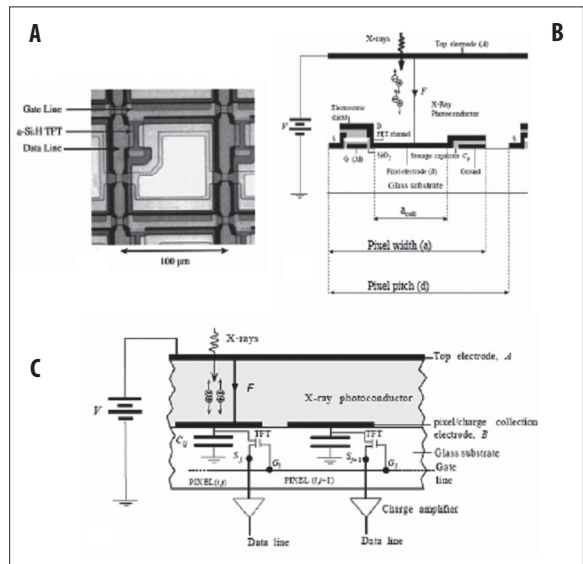
**Figure 9.** Construction of digital detectors – direct and indirect detection (according to MEDTECH and Performance Assessment of DR Systems, JA Seibert, Ph.D. UC Davis Medical Center Sacramento, CA, <http://www.aapm.org/meetings/03AM/pdf/9787-48370.pdf>).

25% of the deposited signal between 10 minutes and 8 hours period subsequently to the exposure. After that time frame, the fading slows down.

**DR and DDR Digital Systems**

In radiography with digital image detectors, the most common solution are panels made of amorphous silicon or selenium (indirect digital systems) and panels based on a matrix made of electrodes separated by a layer of insulator and the active components, such as thin-film transistor (Figures 8, 9).

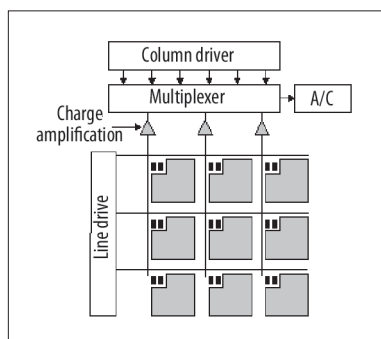
Detectors, which consist of photoconductors, such as amorphous silicon or selenium, constitute the main part of indirect digital systems. Layer of silicon detector contains a matrix of receptors, each equipped with its own control component (transistor or diode) and corresponding to one pixel of the image. Regulating (control) systems are responsible for the process of data reading: line after line, electrical signals are intensified and converted into a digital form. Silicon itself is not sufficiently sensitive to energy of X-rays radiation used in diagnostic imaging. Therefore, silicon layer is covered with a layer of scintillation material, such as cesium iodide (CSI). CSI is characterized by a needle-like structure of a crystal, causing less side-scattering of light and ensuring



**Figure 10.** Direct digital system detector: (A) microphotography, (B) the physical structure of a single pixel of TFT matrix (C) a schematic diagram of the structure of two pixels (according to Mammographic detectors, G. PANAGIOTAKIS UNIV OF PATRAS).

higher resolution of the imaging system. The thickness of the CSI crystal with its needle-like structure can be adjusted to the desired sensitivity of the system (ensuring proper level of absorbance of x-ray radiation), with the maintenance of high spatial resolution at the same time. Photodiodes (Si: H), located under a layer of scintillation material, convert the optical signal into an electrical signal (charge), which is accumulated in a capacitive element of a pixel.

In the direct digital imaging system, the detector is made of photoconductors characterized by a high atomic number (e.g., Se or PbI2). They cover an active area of the matrix. That kind of structure forms a layer of photoconductors which directly converts X-ray radiation incidents into charge carriers, drifting to the collecting electrodes. The main advantage of direct digital systems, comparing to CR systems and indirect DR systems, in terms of image quality, is the lack of effects from the light photons scattering at the detector material. Electric charge, generated as the effect of x-rays radiation, is collected by a single electrode, which makes the side-scatter (diffusion) effect not significant for the process of image creation. Additionally, detector absorption efficiency can be maximized by an appropriate selection of the material of photoconductors, calibration, and a proper thickness of the layer of capacitive elements (Figure 10).



**Figure 11.** The sensor matrix construction in displays and the methods of readout control (according to Medtech).

An active matrix consists of  $M \times N$  number of pixels. Each pixel has three basic elements: the TFT switch, pixel electrode and capacitor. Active matrix is determined by the pixel width ( $a$ ), width of pixel collection ( $a_{coll}$ ) and the distance between pixels (pitch) ( $d$ ) (Figure 10).

TFT elements function as switches, for each pixel individually, and control the charge. Each line of pixels is simultaneously electronically activated during the reading process. Normally, all TFT elements are deactivated, allowing the accumulation of the charges on pixels electrodes. Data can be obtained by external electronics and controlling of the TFT status by software. Each TFT contains three electrical components: Gate (G) controlling "on" or "off" TFT status, Drain (D) connecting the pixel electrode and the pixel capacitor and Source (S) connected to a collective data transmission line. When the gate line is activated, all the elements of TFT in a particular row are 'on' and the charge collected on the electrodes is read from the data line. Parallel data are multiplexed into serial data, discretized and transferred to a computer to create the image (Figure 11).

An indisputable benefit of digital image acquisition is the possibility of post-processing.

### Factors Determining Image Quality

- **Detection Efficiency** – in the SF ("screen film"), CR (phosphorus imaging plates) and DR (digital systems) imaging systems, quantum efficiency is determined by thickness, density and structure (composition) of the absorber (image detector).
- **Dynamic Range** – for high quality imaging in digital radiography, image detector must have a good contrast resolution in a wide spectrum of X-radiation exposure intensity. Dynamic range of the imaging system is determined by the ratio of the largest and smallest input intensities, which can be visualized. The smallest useful value of intensity is limited by the noise level of the system, while the highest value of intensity depends on detector saturation level.
- **Spatial Sampling** – all digital detectors sample the permanently fluctuating stream of X-rays at the input, at discrete locations, separated by gaps (pitch). In CR systems, the spacing between samples is the distance between adjacent positions of the laser beam during reading process from the imaging plate. In DR systems, pitch is the distance between centers of the spaces separating each of detecting elements. The spatial frequency in sampling, determines the digital system's ability to display high-frequency fluctuations in X-ray stream. If the X-radiation stream interacts with receptor, generating the data of frequencies higher than the Nyquist frequency, and modulation transfer function (MTF) for these frequencies, prior to sampling, is not fading, then false signal can appear in the image at low frequencies.
- **Spatial Resolution** – is the ability of imaging system to visualize two adjacent structures as separate image elements, or a clear edge marking in the image (sharpness). Losses in the spatial resolution occur due to blurring caused by geometric factors (e.g., size of a focus, scattering of light in the receptor), the effective area of the detector determined by the size of aperture, patient's movements in relation to the source of X-radiation, image detector, the thickness of the detector elements, screen, CSI crystal thickness and density of data reading.
- **Noise** – it can be defined as fluctuations in the image, which do not correspond to differences in X-radiation absorption by objects. A measure of noise may be determined by estimating the noise power spectrum (NPS), which describes the correlation of spatial frequency and noise. The noise in the image is dominated by quantum (shot) noise resulting from quantum fluctuations in the X-ray and data digitization (in case of digital systems). However, all image receptors contain internal sources of noise, such as noise coming from the film grain and electronic noise in the CR and DR systems. The internal noise of the detector, with established correlation corresponding to place on the receptor, results from a spatial difference in the intensifying screen thickness, in SF system, from light detection efficiency dependent on the location on plate readers in CR systems, and differences in preamplifying in DR systems. One of the advantages of digital imaging is that the internal noise of detector can be digitally eliminated by post-processing (obtaining valuable diagnostic image). Deterioration of the image in radiography is also conditioned by the scattering of radiation, which is another source of noise and contributes to decreasing of image contrast. The solution to this problem is the use of anti-scatter grids placed in front of the image detector. Using the grid is especially important in CR systems, due to an increased sensitivity to scattered radiation of barium halide (K-edge is approximately 35 keV), in relation to the SF screens which contain gadolinium oxide sulphide (K edge is approximately 50 keV). In the scanning systems (field slot-scan) on the other hand, DR detectors are able to "cut" the scattered radiation out from recording and therefore do not require the use of anti-scatter grid.
- **Contrast resolution** – refers to the value of the signal difference between the examined structure and the surrounding. It is the result of differences in X-ray absorption in the examined tissues. It is expressed as a relative difference in brightness between the relevant areas in the digital image shown on the monitor. Radiographic

contrast is determined by the contrast of the object and receptor sensitivity. It is strongly reliant on the energy spectrum of X-ray radiation and the scattered radiation phenomenon. However, in digital imaging, contrast in the image can be changed by setting the visualization parameters, independent of the acquisition conditions.

- **Detection quantum efficiency (DQE)** is a parameter that describes the image receptor, considering its efficiency of radiation detection, spatial resolution and noise level. DQE describes the relative efficiency in maintaining SNR level (signal – to – noise ratio), possible to achieve in the imaging process. This parameter is defined as  $SNR_{out}^2/SNR_{in}^2$ , where  $SNR_{in}^2$  means signal – to – noise ratio of exposure impact on receptor and numerically equivalent to the input stream. Thus, DQE can be described as the efficiency of SNR transmission by the system, the effectiveness of which translates into the quality of detection and image acquisition.

### Quality Assurance in Diagnostic Imaging

Assuring quality in imaging is a process of deliberate acting in order to obtain the best possible diagnostic images, that enable an appropriate clinical evaluation. It is important for the image to contain enough data with the least patient's exposure to ionizing radiation. To fulfill these objectives, a continuous monitoring of the diagnostic imaging process is necessary, in accordance with the requirements of the regulations and quality standards for medical equipment. For this purpose, an appropriate acceptance testing is carried out, as well as routine performance tests on a basic and specialist level, controlling, analyses of the rejected images, and monitoring of the image acquisition process.

Acceptance testing, performed to verify whether the equipment and rooms meet the technical requirements, provide an utter and objective assessment of the procedures and equipment condition. However, the main purpose of routine performance evaluation (basic and specialist) is to certify whether the equipment and procedures are maintained in an optimal and constant range.

Tests connected with image detector, in all three systems presented above, include:

- In analog radiography: cassette tightness, inspections of the developing process (darkroom quality control), film storage conditions, film-screen contact test, anti-scatter grid, high-contrast resolution, low-contrast resolution, uniform sensitivity of intensifying screens.
- In computed radiography: noise (signal – to – noise ratio, SNR), uniformity (imaging plate test), anti-scatter grid, erasure thoroughness, high-contrast resolution, low-contrast resolution, defective pixels analysis (bad pixel map), uniform sensitivity of the plates, fading, imaging plate throughput, linearity and automatic response.

### Analog Radiography

1. **Cassette tightness test:** all clinically used cassette and the testing cassette are subject to this test. It is carried

out by placing "loaded" cassettes, side by side, in a fully illuminated room. They all should be developed after 15 minutes. There should be no dark, indicating worn seals, areas on the film. Faulty cassettes should be replaced.

2. **Developing process inspection** (darkroom quality control): the purpose is to control the repeatability of photochemical processing, proved by the constancy of obtained image parameters. Three basic parameters are taken from the characteristic curve (Fig. 2): the minimum density  $D_{min}$ , sensitivity  $S$ , and a mean gradient  $g$  ( $g=(D1-D2)/(P1-P2) * 0.15$ , Art. 2a). Measured values should be within the range of tolerance specified in the Journal of Laws, No. 194, item 1625.
3. **Film storage conditions:** this test is performed using a thermometer and hygrometer to measure the temperature and humidity in the film storage area. Measures should be according to the manufacturer's instructions, placed on packaging of the films.
4. **Film-screen contact test:** this test is carried out for all the cassettes, using a specially designed phantom (films should be loaded in a cassette at least 15 min prior to the test and the cassettes should be placed in a upright position). Cassettes should be placed within the X-ray beam, and covered with the wire mesh (the whole surface should be covered). Conditions of the exposure are selected manually in order to achieve the optical density value consistent with recommendation of the manufacturer of the test. The number and size of dark areas should be checked (places of no film-screen contact). Acceptable size of the "no contact areas" is given in appropriate regulations (Minister of Health Regulations; Journal of Laws No. 194, item 1625).
5. **Uniform sensitivity:** in SF systems, a test verifying the sensitivity of intensifying screens (cassettes) should be performed. The test is based on imaging of a homogeneous phantom with automatically set exposure in clinical conditions. Optical density value at the point of reference is measured on the raw image. Evaluation of uniformity of the sensitivity bases on a comparison between optical density values obtained for each cassette. Differences should not exceed the range specified in Minister of Health Regulations (Journal of Laws No. 194, item 1625). At the same time, differences in values of the input air kerma for each cassette should not exceed 5%.
6. **Anti-scatter grid:** attenuation coefficient of the anti-scatter grid is assessed by measuring the air kerma, placing the detector in the front of the grid (in relation to the source) and behind the grid, taking into account a correction related to optical density obtained for the exposed film placed in the front and behind the grid, in relation to the source. The ratio of these measurements, taking into account the correction for measurement distance in both configurations, determines the attenuation of x-rays radiation passing through the grid. The coefficient of the grid should be less than the 3. The grid is also tested visually, for any structural damage or shift disturbance (in case of mobile grids), which can cause image artifacts.

**7. Resolution of the imaging system:** a test is performed using a resolution phantom, which is placed directly (as close as possible) on the image detector. When assessing the resolution of the system, it is desirable to use several phantoms in the following configuration: in the middle of the beam axis and on the edges of the detector. It enables us to measure the resolution for any size of the detector, considering imaging within the beam axis and edge conditions (off the axis). The value of the resolution should be close to the value given in the manufacturer's specification.

### Computed Radiography and Digital Radiography (CR and DR Systems) (joint tests):

1. **Noise test:** based on the measurement of a mean pixel value and standard deviation in the reference ROI (Region of Interest) for an unexposed detector. In case of systems with a linear response, SNR should be estimated and placed on a graph of function of SNR<sup>2</sup> over input surface kerma (it can be determined by tests of the detector response function). Obtained measures (points) allow to draw a line of best fit (linear regression trend) in order to calculate a correlation coefficient. Noise test should be carried out for different anode-filter configurations used in clinical practice. The derogation from linearity is a measure of quantum noise (system electronics). For logarithmic systems, this graph shall define the relationship between standard deviation and inversed input surface kerma of the air. For the measurement points, a line of best fit and correlation coefficient should be determined. Shift of the point intersection with the kerma domain axis on the graph is a measure of quantum noise in these systems. The results of both systems should be comparable with previous results.
2. **Uniformity:** in order to assess the uniformity of the detector response, an image of a homogeneous test phantom should be performed, covering the whole area of imaging. Exposure parameters in this test should correspond to clinical conditions. On the obtained raw image, the mean pixel value and standard deviation in the reference ROI should be calculated. These parameters should be also evaluated for areas of readout localized in different parts of the detector. The mean pixel value for the whole image should be calculated, as well as SNR for all ROIs. Results obtained for each ROI should be compared with mean values. Maximum acceptable aberration should not exceed 15%.
3. **Anti-scatter grid test:** performed as in analogue radiography. For systems with direct digitization, the test is not performed.
4. **Erasure thoroughness/DR detector reset:** The test applies to all available imaging plates and DR detectors, which should be erased (reset) in a full cycle, to get rid of any signals that cause artifacts. The detector prepared in such a way should be scanned in order to check whether the received image is "clean" The whole procedure must be repeated, if artifacts or remnants of the previous image appear on any of the detectors.
5. **Resolution of the imaging system:** resolution phantom is used, which is placed directly on the detector (using

several phantoms placed in the middle of the beam axis and on the edge of the detector enables the measurement of resolution for any kind and size of the detector in both directions of scanning). The measured resolution should be approximate to the value specified by the manufacturer. If the resolution value deviates by 10% from the specified value, the system must be corrected. Resolution of the system is affected not only by the size of the detector but also the algorithm of high-contrast processing. In digital imaging systems, the resolution test should be performed for the clinically used settings of exposure, and image formats usually applied. Resolution assessment is based on the MTF analysis (objective method) or visual assessment defined as the number of pairs / mm (subjective assessment). Resolution in CT systems is also determined by the size of the laser beam cross section, as well as oscillations and focusing of the laser.

6. **Low-contrast Resolution:** the test is performed for each size of the detector, using phantom with low-contrast elements. Three exposures for three different time periods should be performed. Visibility of the low-contrast elements is to be evaluated and compared with the results of baseline measurements. In the process of image acquisition, mathematical high-contrast algorithm or edge improvement algorithm (software filter) should be applied. As the result of that test depends on the type of phantom and objective assessment of the tester, the assessment of several images or by several testers should be implemented as a standard routine.
7. **Defective pixels test (Bad pixel maps):** An evaluation of these artifacts is carried out using raw, "pre-processed" image – this image is inspected for the presence of uncorrected bad pixels (hot and cold). Each country enforces its own regulations regarding the amount of bad pixels in the image. Information on the uncorrected defective pixels should be specified by the manufacturer, and their number in the test should not change when compared to the original. In this test, image is obtained as a result of exposure of a homogeneous test phantom under clinical conditions. The analysis of the results can be conducted via visual assessment or searching the ROI of signal deviation exceeding 20%.

### Computed Radiography

1. **Uniform sensitivity:** in CR systems, a sensitivity test of imaging plates should be carried out. The test is based on homogeneous phantom imaging under automatically selected exposure in clinical conditions. The mean pixel value and standard deviation in ROI of reference is measured on the 'raw' image. The assessment of the uniform sensitivity of utilized imaging plates is based on a comparison of SNR. Differences should not exceed 10%. At the same time, the values of the input air kerma obtained in the test for each plate should not differ by more than 10%.
2. **Evaluation of fading phenomenon:** This test is performed on images obtained from a homogeneous phantom exposure in the clinical conditions. These images are subject to acquisition in different time intervals after plate exposure (1 min, 2 min, 5 min, 10 min, 30 min;).

For images obtained in this method, the mean pixel value in ROI of reference can be determined. The results are to compare with the reference values of the acceptance tests.

3. **Phosphor imaging plate throughput:** in this test, 4 plates of equal size should be exposed, with a standard geometry of the system. Plates, exposed as described, are to be put one by one to the reader (without time delay). Throughput rate should amount to approx. 10% (for each plate) of the value given in the specification.
4. **The linearity and automatic response:** this test determines the response of the detector and information retrieval system to the changes in exposure. The test is conducted by setting 3 different times of exposure and measuring the air kerma, which is subsequently recalculated relatively to the surface of the detector. For each exposure, three independent images should be

performed, with readout delay of 10 minutes. The whole process should be repeated 3 times. The calculated value of the exposure time should be within 20% (for each plate) in relation to the value mentioned in the specification or within 10%, as compared to the mean value for all tested plates. Measuring range used to evaluate the detector response function falls between 0.1 of the standard exposure time and quintuple of that time. While analyzing the results, a graph of input surface kerma function over a mean pixel value of ROI should be drawn. Correlation coefficient of the relation between the regression line and real value points should be higher than 0.99. The point of intersection with mean pixel value axis (Y) determines the offset of the pixel value.

In addition, in CR systems, an analysis of trends for the values of the measured parameters (especially for log-linear configuration) must be performed, referring to the values of the basic tests.

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