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A comparison of modulation transfer function of indirect digital radiography systems

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ABSTRACT

Background: There are several parameters to characterize the quality of digital image. Resolution is one of the main parameters of an image quality. Modulation transfer function (MTF) is a quantitative measurement describes image resolution properties of an imaging system as a function of the spatial frequency. Several reports compared the spatial resolution between direct and indirect digital radiography (DR) systems proved that direct DR systems had better spatial resolution. Moreover, they also compared the different phosphor detectors of indirect DRs. However, to our knowledge, there is no report that compares the same gadolinium oxysulfide (GOS) phosphor detectors of indirect DR from different DR system manufacturers.

Objectives: To compare MTF of flat panel detectors (FPDs) indirect conversion using GOS phosphor with fixed focal spot size under radiation beam condition according to International Electrotechnical Commission (IEC) RQA5 standard.

Materials and methods: Three indirect FPDs from 3 DR manufacturers i.e. detector A, detector B and detector C were used in this study. Measurement tests for spatial resolution evaluating were performed by means of a set of 30 groups of bar patterns with different spatial frequencies which vary increasing order and express as line pairs per unit distance (lp/mm). MTF can be performed from a bar pattern within the image file by elaboration software AutoPia (Auto Phantom image analysis). Frequency at the 0.1 point of MTF was applied with this limiting spatial resolution.

Results: Three FPDs had similar MTF shape. All of MTF values from detectors were decreased with increasing spatial frequency from detector A, B, and C, respectively. This can be sorted in descending order as follows. MTF showed that detector A demonstrated both the highest contrast resolution and spatial resolution. Nevertheless, detector B and C had the same contrast resolution, yet the spatial resolution of detector B was better than that of detector C. Spatial frequency reflects the limiting spatial resolution (MTF=0.1) of detector A, B, and C, at 4.40, 4.02, and 3.77 lp/mm, respectively.

Conclusion: The bar pattern method with an automatic software analysis can be simply obtained MTF result. Test of MTF in beam quality as recommended in IEC RQA5 standard of three FPDs show that spatial resolution sorted in descending order were through detector A, B and C, respectively.

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Introduction

There are several parameters for characterizing the quality of a digital image. Resolution is one of the main parameters of image quality.[1–3] In a digital radiography, resolution consists of spatial resolution and contrast resolution.[4] Spatial resolution describes the ability of medical imaging process to discriminate small objects that are close together.[5] This depends on pixel size in that the smaller the pixel size is, the higher spatial resolution becomes. Spatial resolution is affected by several image processing factors, objects and motion blurs, focal spot size, and receptor blur. Meanwhile, contrast resolution is the ability of an imaging system to discriminate an object with small density differences and/or differentiate small attenuation variety on the image.[5] This is affected by tube collimation, number of photons, noise, scatter radiation, beam filtration, detector properties, and algorithmic reconstruction used.[4]

To evaluate the resolution, both qualitative and quantitative measurement methods can be performed. Qualitative methods are based on human observations. Visibility measurement of line pair test object is one of the methods which has been used for a long time especially in film-screen imaging. Introduction to digital imaging systems allows access to image information directly via the DICOM format and this should permit a move to more quantitative measure of image quality.[6] Modulation transfer function is a quantitative measurement that describes the image resolution properties of an imaging system as a function of the spatial frequency.[7] Considering a patient's body that consists of fine objects and coarse objects, these objects can be represented as spatial frequencies (line pairs per mm or lp/mm), where fine and coarse objects generate high and low spatial frequencies, respectively. While the high spatial frequencies represent fine detail or sharpness, the low spatial frequencies represent object contrast information. The image would contain both sharpness and contrast (intensity grayscale values). MTF is a graph of the contrast plotted as a function of spatial frequency. Maximum of MTF value at 1.0 represents a perfect transfer of spatial and contrast information. All digital imaging systems have the limiting resolution whose spatial frequency limit is obtained at an MTF value of 0.1. A system with higher spatial frequency at an MTF of 0.1 will show better spatial resolution.[8]

Measurement of MTF for various detectors demonstrates decreasing MTF with increasing spatial frequency.[7] A higher MTF value at a higher spatial frequency means the detector provides better spatial resolution. Furthermore, a higher MTF value at a lower spatial frequency means that it provides better contrast resolution. MTF is the most important parameter which plays an important role to evaluate resolution for digital radiography systems.

There are three methods i.e. bar pattern, slit pattern, and edge pattern to accomplish the MTF measurement. The slit test uses the Fourier transform of a finely sampled line spread function from a slightly angulated slit to determine MTF. While, the edge test uses the edge spread function from an opaque object with a straight, sharp, and smooth edge to determine MTF. The edge test method is widely used to measure MTF of digital X-ray detector.[1] There was a report showing that MTF obtained by edge method compared to bar pattern method was not statistically different. Although, the slit test is very high precision method, but it requires a time-consuming. Moreover, slit test and edge test require a complicated alignment. Therefore, bar pattern is a simple method that can be used to the routine quality control.[1,9,10]

The traditional field of projection X-ray imaging went through a significant transformation into a digital age during the last decade. Digital radiography (DR) has become an everyday technique in a clinical practice since the beginning of this century. In DR system, the image is obtained immediately after X-ray examination of the patient has been performed. Its popularity around the world is mainly a result of the increased availability of flat panel detectors (FPDs) on the market. There are two types of FPD which have been developed i.e. direct and indirect systems; first, a direct type FPD which converts the X-ray signal into an electrical signal by a thin film transistor (TFT) covered with Selenium (Se) in a photoconductor.[11] It is a device with high resolution,[12] and second, is an indirect type FPD phosphors. For example, one of them is Thallium activated Cesium Iodide (CsI(TI)) on TFT which converts an X-ray signal into a light signal and converts it into electrical signal later. Generally, the majority of indirect FPDs available on the market employ an x-ray converter made of Gadolinium Oxysulfide (GOS) phosphor. Several reports through these DR system devices compared the spatial resolution between direct and indirect DR systems and proved that direct DR systems have better spatial resolution.[1-3,13,14] Moreover, they also compared the different phosphor detectors of indirect DRs.[12] However, there has never been any report that compares the same GOS phosphor detector of indirect DR from different DR system manufacturers. This gives rise to this research study with a specific purpose as follows.

Purpose of this research study is to compare the MTF of flat panel detectors indirect conversion using GOS phosphor with Leeds test objects medical imaging phantoms (TOR CDR).[15] The images are acquired from three detectors with the same X ray generator with a fixed focal spot size because the focal spot size also affects spatial resolution.[9] The radiation beam condition is operated according to IEC RQA5 standard because energy of X ray affects to spatial resolution as well.[9] The MTF were analyzed by software (AutoPIA from Leeds University) from bar pattern images.[16]

Materials and methods

1. Digital radiography detectors studies

Three indirect flat panel detectors (FPD) i.e. detector A, detector B, and detector C from 3 DR manufacture were used in this study. All of them are indirect conversion units that used GOS phosphor boned to a light-sensitive thin film transistor (TFT) array formed from amorphous silicon (a-Si). Basic technical parameters for the systems are shown in the table 1.

Table 1 Basic parameters for each FPD from 3 DR system manufacturers.

FPD	Image area (cm x cm)	Matrix size	Pixel size (mm x mm)	Bit depth (bits)
A	35x43	2304x2880	0.15x0.15	12
B	35x43	2560x3072	0.14x0.14	14
C	35x43	2466x3040	0.14x0.14	14

2. Test equipment

The device used for acquiring an image in this study is TOR CDR phantom from Leeds University. Measurement tests for spatial resolution evaluating were performed by means of a set of 30 groups of bar patterns with different spatial frequencies which vary an increasing order and express as line pairs per unit distance (lp/mm).[16] Spatial frequency values for all bar pattern are shown in Table 2.[17]

Table 2 Spatial frequency values for bar patterns of TOR CDR.

Group number	Spatial frequency (lp/mm)	Group number	Spatial frequency (lp/mm)
1	0.50	16	2.80
2	0.56	17	3.15
3	0.63	18	3.55
4	0.71	19	4.00
5	0.80	20	4.50
6	0.90	21	5.00
7	1.00	22	5.60
8	1.12	23	6.30
9	1.25	24	7.10
10	1.40	25	8.00
11	1.60	26	8.90
12	1.80	27	10.00
13	2.00	28	11.10
14	2.24	29	12.50
15	2.50	30	14.30

After TOR CDR phantom was imaged, recorded with DICOM file, and opened with elaboration software AutoPia (Auto Phantom image analysis),[16] the MTF could be performed from bar pattern with different spatial frequencies that varied in increasing order and expressed as line pairs per unit of distance (lp/mm) of distinguishing structure of different sizes according to Droege and Morin.[18] Then, MTF was plotted automatically. Details of characteristics of image and detector can be retrieved from DICOM header for analyzing and reporting. An output data can be saved as CSV file for analyzing later. A radiograph of bar line pair pattern from TOR CDR phantom and MTF analysis result with the frequency at MTF of 0.1 to determine the limiting spatial resolution[19] as shown in Figure 1.

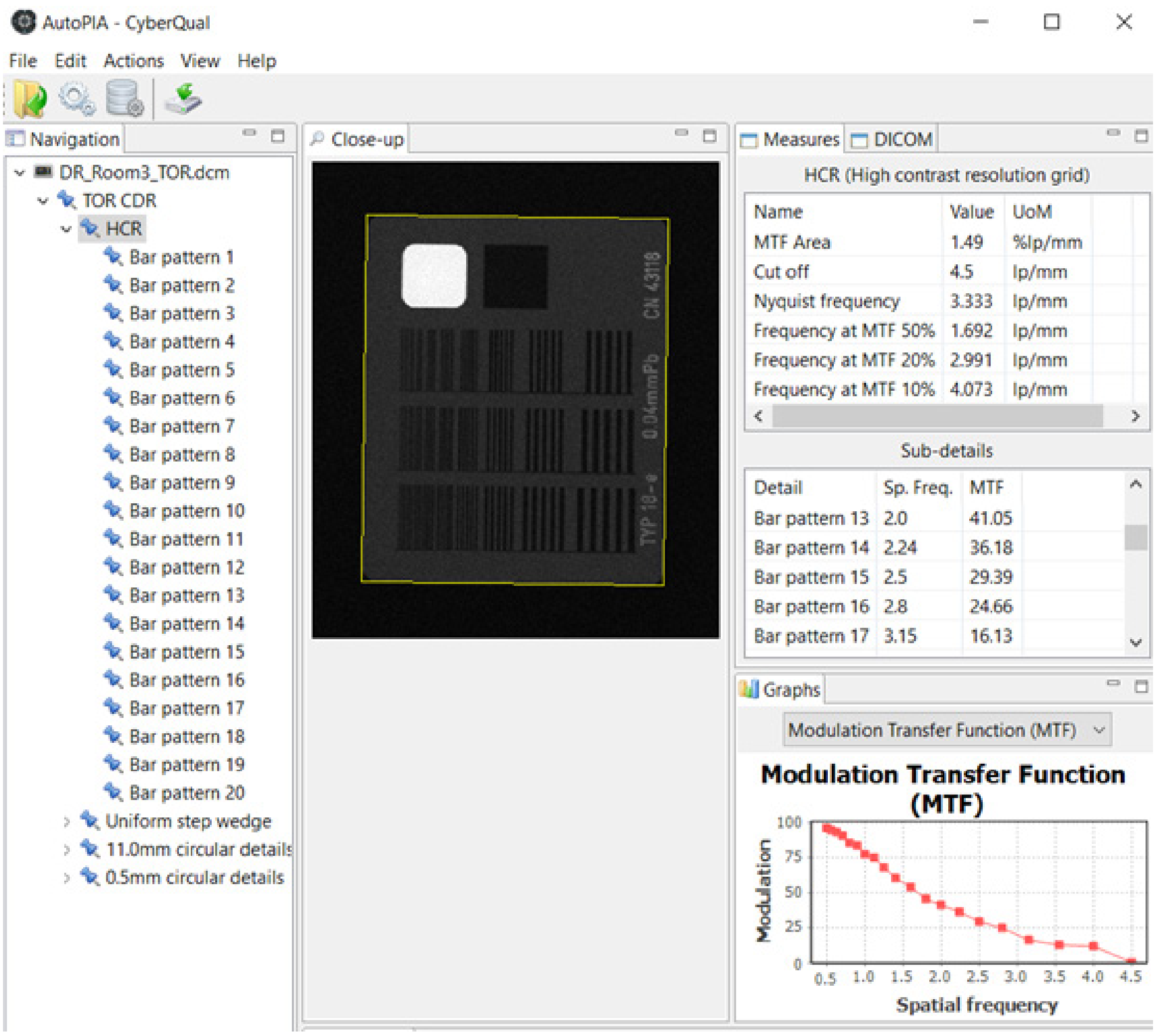

Figure 1*. A radiograph of bar line pair pattern from TOR CDR phantom and MTF analysis result.*

3. Beam condition

The X ray beam condition is set up according to the IEC RQA5 standard which requires a 21 mm aluminum filter block in the beam. The IEC guidelines require two beam-limiting Pb apertures for MTF measurement. Based on those guidelines 2 mm thick, Pb sheets were used to construct a 5x5 cm^2 and 16x16 cm^2 apertures. The 5x5 cm^2 and 16x16 cm^2 apertures were placed along the beam axis at 39 cm from the focal spot and 12 cm from detector, respectively as in Figure 2.[20] With test phantom and collimators in place, a half value layer (HVL) of 6.88 mmAl was achieved at 70 kVp[21] and exposure measurement for HVL calculation were made by Piranha X ray testing device (RTI R 100 dose detector).

As the focal spot size affects to spatial resolution, X ray generated from mobile unit is used to fix a nominal focal spot size at 0.60 mm for all test images in this study. The most interesting range for characterizing detectors for a digital radiography with about 1 µGy to upper limit of around 10 µGy.[22] In this study the technique was fixed at 70 kVp 20 mAs that provided 10 µGy.

4. Image acquisition

TOR CDR phantom was placed in contact with the detector cover, aligned with the central axis and perpendicular to cathode and anode of the X ray tube. All images were acquired using a 180 cm source-to-detector. The images were acquired 3 times for each detector with an average data to calculate MTF. All images used in this work were acquired with non-processing.

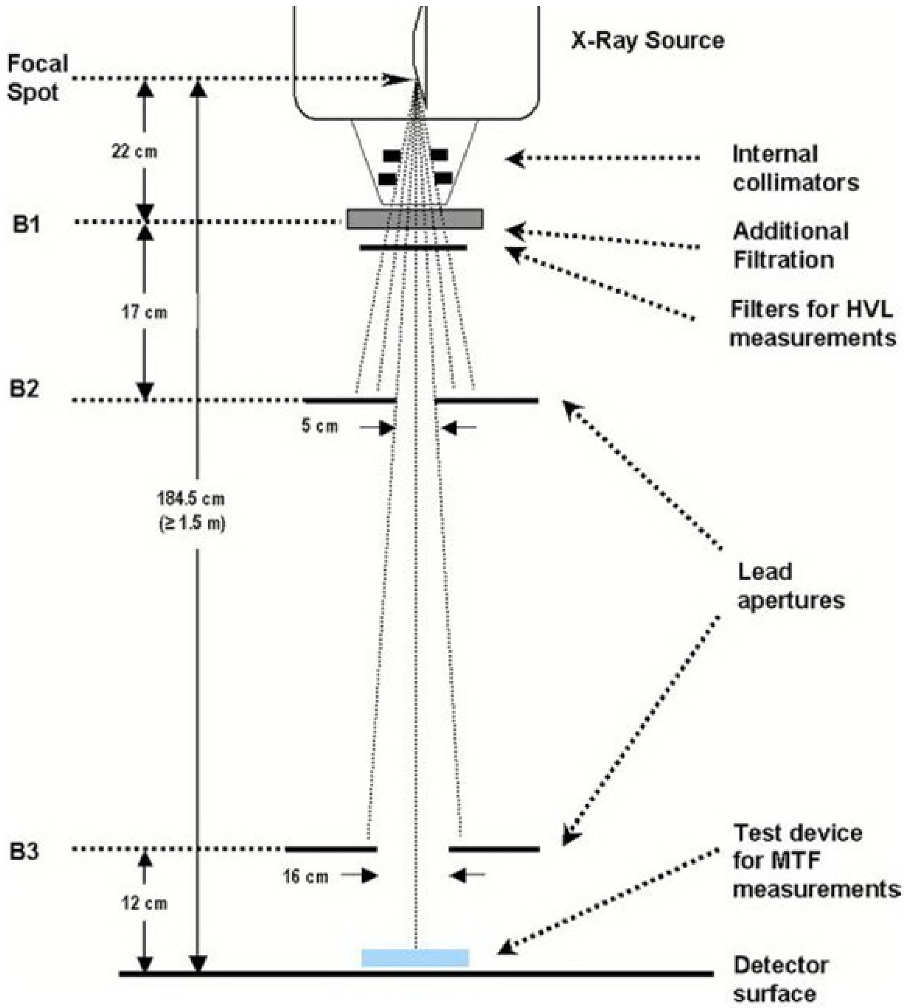

Figure 2. *X ray beam condition according to the IEC RQA5 standard.*

Results

The result shows that 3 FPDs have similar MTF shapes. MTF values from all of detectors decrease with increasing of spatial frequency as shown in figure 3. This can be sorted in descending order from A, B, to C. The MTF value of detector A at frequency 0.5 lp/mm is 0.951 while detector B and C are 0.895 and 0.891, respectively, as shown in table 3. This means that detector A is the highest contrast resolution. Although detector B and C have the similarly high contrast resolution, detector B has a better contrast resolution than detector C. The spatial frequencies of detector A, B, and C at 0.8, 0.5, 0.2, and 0.1 points of MTF had the same tendency as shown in table 4. The spatial frequency reflects limiting spatial resolution (MTF=0.1) of detector A, B, and C, at 4.40, 4.02, and 3.77 lp/mm, respectively. These confirmed that detector A has both the highest contrast resolution and spatial resolution.

Discussion

All detectors in this study were Indirect DR with the same GOS phosphor. In general, DR has better contrast resolution than conventional radiography and CR because of more dynamic range. Normally contrast resolution also depends on gray scale bit depth. Detector with high bit depth obtains high contrast resolution. However, the result of this study detector A (bit depth 12) obtained contrast resolution higher than the others (bit depth 14) as shown in table 3. There may be some factors can be improved contrast resolution. Moreover, the contrast resolution of detector can be considered from MTF curve in the low spatial frequency zone (0 to 1.5 lp/mm) as shown in Table 3 and Figure 3.

Another result showed that detector A (pixel size 0.15 mm) obtained better spatial resolution than those of the others (pixel size 0.14 mm) as shown in Table 4. As we know spatial resolution depends on pixel size of the detector especially in CR, but in DR with smaller pixel size do not necessarily obtains better spatial resolution because other factors such as light scatter within the detector contribute to degradation of spatial resolution.[11]

As a problem of indirect DR comes from spreading of light on surface of the phosphor leading to a gradation of spatial resolution,[5] this problem has been solved by performing a new scintillator design from an X ray penetration-side photo detection (PS) to an X ray incident-side photo detection (IS) by some DR system manufactures. Benefit of this configuration is a reduction of light attenuation and blurring effect. The use of IS system is applied to improve spatial resolution. The use of IS system is also applied to improve contrast resolution by increase thickness of scintillator layer thus increase number photons of light and improving to increase sensitivity of the system.[12,23]

Thus, result from detector A which obtained much more contrast and spatial resolution can be from the same reason. Therefore, MTF can be a useful tool for comparing image quality of different radiographic systems. More importantly, the method of bar pattern phantom with automatic software has various advantages. It is simple to evaluate MTF which is useful for day to day job of applying by personnel in the health care services. The achievement of measurements in accordance to the most common standards among staff in radiology department can be developed as a new simple skill. As a result, it is important to select the best of medical imaging systems and perform the test to maintain image qualities which this newly discovered test can be achieved periodically in very short time for monitoring a system and ensuring the image quality.

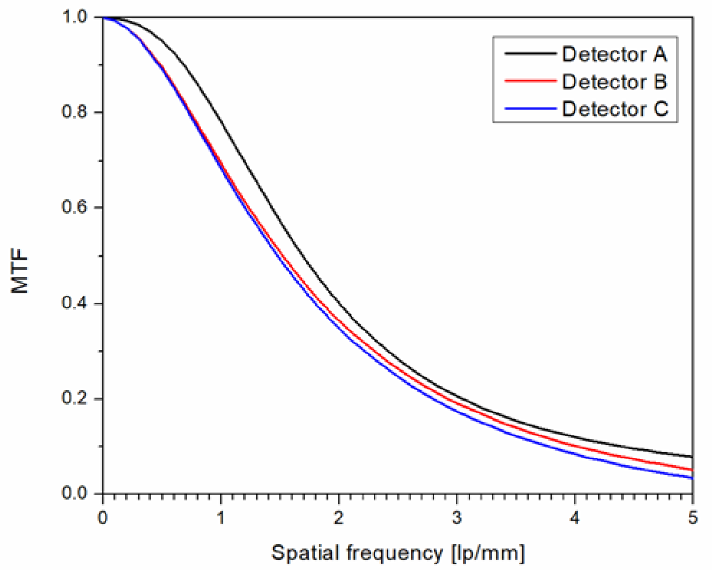

Figure 3. *MTF values from all of detectors.*

Table 3 MTF from the three FPDs at different spatial frequency.

Spatial frequency (lp/mm)	MTF		
	Detector A	Detector B	Detector C
0.5	0.951	0.895	0.891
1.0	0.782	0.694	0.684
1.5	0.572	0.506	0.493

Table 4 Spatial frequency from the three FPDs at different values of MTF.

FPD	Spatial frequency (lp/mm)			
	MTF at 0.8	MTF at 0.5	MTF at 0.2	MTF at 0.1
A	0.96	1.69	3.04	4.40
B	0.74	1.52	2.93	4.02
C	0.73	1.48	2.80	3.77

Conclusion

This research paper confirms that MTF measurement can be simply obtained through the method of using bar pattern with automatic software analysis. To test MTF in beam quality as recommended in IEC RQA5 standard of three FPDs proves the spatial resolution in descending orders range from detector A, B to C respectively.

Conflicts of interests

The authors declare that they have no conflict of interest.

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