

## Introduction of a New Parameter for Evaluation of Digital Radiography System Performance

### Abstract

**Background:** The aim of this study was to compare the image quality and radiation doses in various digital radiography systems using contrast-detail radiography (CDRAD) phantom. **Methods:** The image quality and radiation dose for seven different digital radiography systems were compared using the CDRAD phantom. Incident air kerma (IAK) values were measured for certain exposure settings in all digital radiography systems. The images from the CDRAD phantom were evaluated by three observers. The results were displayed in the form of a contrast-detail (CD) curve. In addition, the inverse image quality figure (IQF<sub>inv</sub>)-to-IAK ratios were used for quantitative comparison of different digital radiography system performance. **Results:** Results of this study showed that the CD curves cannot be suitable criterion for determining the performance of digital radiography systems. For this reason, IQF<sub>inv</sub>-to-radiation dose (IAK) ratios in a fixed radiation condition were used. The highest performance in terms of producing high-quality images and low radiation dose was related to X-ray unit 1 and the lowest performance was for X-ray unit 5. **Conclusion:** The ratio of IQF<sub>inv</sub> to IAK for performance evaluation of digital radiography systems is an innovation of this study. A digital radiography system with a higher IQF<sub>inv</sub>-to-IAK ratio is associated with lower patient dose and better image quality. Therefore, it is recommended to equip the new imaging centers with the systems that have higher IQF<sub>inv</sub>-to-IAK ratios.

**Keywords:** Contrast detail, contrast-detail radiography phantom, digital radiography, image quality, radiation dose

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### Introduction

In recent years, digital radiography systems have been rapidly expanding and replacing analog radiography systems in many radiology departments.<sup>[1]</sup> Based on the difference in X-ray recording and detection, digital radiography systems are usually classified into two categories: computed radiography and flat-panel digital radiography.<sup>[2]</sup> The computed radiography systems are using of storage phosphor screens and reader equipment. These systems were the first step in digitizing the radiography systems.<sup>[3]</sup> The next step for digitizing radiography systems is the flat panel radiography systems, which are classified into two categories of direct and indirect detection systems.<sup>[4]</sup>

The advantages of digital radiography systems compared to analog systems, including flexibility in image display,

wide dynamic range, and digital image management using picture archiving and communication system, were indicated in the previous studies.<sup>[2,3,5]</sup> However, in digital radiography systems, there is a direct relationship between image quality and patient radiation dose. In these systems, noise of image increases with decreasing radiation parameters, resulting in reduced image quality and vice versa. However, when the radiation parameters increase, the image quality improves but this will unconsciously increase the dose of patients.<sup>[4,6,7]</sup>

Three parameters affecting image quality include contrast resolution, spatial resolution, and noise. A number of previous studies have compared the image quality in radiography systems using different special phantoms.<sup>[5,8-11]</sup> They have independently investigated each of the three mentioned components of image quality. However, image quality parameters are interdependent and cannot be separately investigated. Contrast-detail (CD) phantoms

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can combine parameters affecting image quality.<sup>[4]</sup> One of the best and most complete of these phantoms is the CD radiography (CDRAD) phantom. This phantom has been used in several studies for different purposes such as comparison of different detectors,<sup>[12]</sup> comparison of dynamic flat-panel detector with a slot-scanning device,<sup>[13]</sup> and comparison of different upgraded analog radiography systems.<sup>[14]</sup>

On the other hand, radiography systems, fabricated by different manufacturers, have different efficiencies in terms of balance between image quality and radiation dose. The best digital radiography system is a system that can produce better image quality with less radiation dose. Some studies<sup>[15,16]</sup> have used the CDRAD phantom to compare the different models of digital radiography systems. However, they assessed image quality and radiation exposure for only chest radiography using CD curves. In addition, in some cases, CD curves cannot be a good benchmark for comparing the performance of digital radiography systems.<sup>[17]</sup> Therefore, the aim of this study was to compare image quality and radiation exposure in various digital radiography systems using the CDRAD phantom with introducing a new parameter.

## Materials and Methods

### Digital radiography systems

In this study, the image quality and radiation dose were compared for the seven different digital radiography systems installed in Iran. The information and characteristics of the studied systems are summarized in Table 1.

### Phantom

In this project, the CDRAD phantom was used to compare the quality of the images obtained from different digital radiography systems. The image of the phantom is shown in Figure 1.

The CDRAD phantom includes a sheet of clear acrylic with dimensions of 265 mm × 265 mm × 10 mm. It consists of a 15 × 15 array of 1.5 cm × 1.5 cm regions, in which holes of different depths and diameters were drilled. The diameter of the holes varies in size from 8 mm to 0.3 mm from top to bottom of phantom with 15 steps increasing logarithmically. These holes have depths from 8 mm to 0.3 mm from right to left in each row. Except for three upper rows of the matrix in which the holes are centrally located, in the remaining rows, two holes are randomly located in one of the four corners of each cell. The arrangement of these holes reduces possible observer bias in predicting the position of holes. The inherent contrast in the CDRAD phantom is created through the difference between density of air and acrylic in each cell.

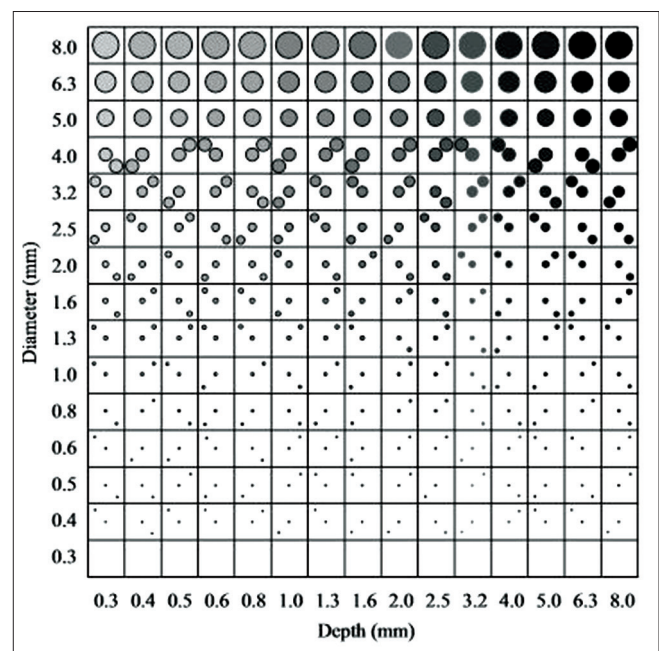


Figure 1: Schematic illustration of the contrast-detail radiography phantom

Table 1: The information and characteristics of the seven different digital radiography systems

X-ray unit	Manufacturer	Brand	Model	Type	Year of manufacturing	Detector manufacturer	Detector name	KVp max	mA max
1	Arcoma, Sweden	Arcoma	Intuition	Ceiling	2010	KONICA MINOLTA	AeroDR P-21 17" × 17"	150	640
2	Arcoma, Sweden	Arcoma	Intuition	Ceiling	2017	PERKINELMER AMERICA	17" × 17"	150	640
3	Apelem, France	Apelem	Da Vinci R302/A Premium	Ceiling	2015	TRIXELL	Pixium RAD4600 17" × 17"	150	630
4	Apelem, France	Apelem	Da Vinci RTC600 Premium	Ceiling	2017	TRIXELL	Pixium RAD4600 17" × 17"	150	630
5	Sedecal, Spain	SEDECAL	MILLENNIUM	Ceiling	2015	TRIXELL	Pixium RAD4600 17" × 17"	150	800
6	Payamed Electronic, Iran	Payamed	DRX-CS	Ceiling	2016	TRIXELL	Pixium RAD4600 17" × 17"	150	710
7	Shimadzu, Japan	Shimadzu	RADspeed	Ceiling	2017	KONICA MINOLTA	AeroDR 17" × 17"	150	630

More details about the CDRAD phantom can be found in the literature.<sup>[18]</sup>

### Imaging parameters

In this study, in order to simulate scatter radiation condition, the CDRAD phantom was placed between two layers of 5 cm of acrylic. For all digital radiography systems, imaging parameters were selected with exposure time of 100 ms, tube voltage of 40, 60, and 80 kVp, tube current of 100, 200, and 400 mA, respectively. Source to image distance was set at 100 cm for all of the exposures. The ranges of the selected exposure factors were similar to those used for conventional X-ray examination. For example, tube voltage of 40 kVp, tube current of 100, and exposure time of 100 ms can be used for radiography of fingers and tube voltage of 80 kVp, tube current of 400, and exposure time of 100 ms can be used for radiography of spine.

Three images were achieved for each exposure setting. Therefore, in total, 189 images were acquired with different imaging parameters in all systems (3 kVp × 3 mA × 3 images × 7 systems).

### Radiation dose measurements

The solid-state dosimeter (RaySafe Xi) was placed at the surface of the acrylic phantom for dose measurements. The incident air kerma (IAK) values resulted from the dosimeter in terms of microgray were measured for each exposure setting in all digital radiography systems. All seven digital radiography systems had passed the quality control tests including accuracy of kVp and mAs. However, in order to compensate for any possible fluctuations in exposure factors, three IAK values were measured for each setting.

### Evaluation of images

The images obtained from the phantom were randomly assigned to three observers. They independently analyzed the images in the same evaluation room with fixed ambient light. Observers were only allowed to adjust the image magnification and did not change other parameters such as brightness and contrast. Observers reported the results as the minimum diameter of the visible cavity in each column of the matrix. Such that, for the different depths (different contrasts), the smallest visible diameter was determined. These results were displayed in the form of CD curves for the seven digital radiography systems in constant radiation parameters. In each CD curve, the just visible cavity depth is plotted against the cavity diameter.

In addition, the inverse image quality figure (IQF<sub>inv</sub>) was used for quantitative comparison of the phantom images. IQF<sub>inv</sub> is defined as:

$$IQF_{inv} = \frac{100}{\sum_{i=1}^{15} C_i \times D_{i,th}}$$

Where  $C_i$  corresponds to the hole depth (contrast) in the column  $i$  and  $D_i$  corresponds to the smallest visible diameter (detail) in this column.

In order to determine the amount of image quality created per dose unit, the average IQF<sub>inv</sub> reported by observers for each system was divided by IAK for the same system in constant exposure setting (60 kVp, 20 mAs). IQF<sub>inv</sub>-to-IAK ratios were compared for different X-ray units.

### Statistical analysis

In this study, one-way analysis of variance (ANOVA) was used to analyze the results of the mean IQF<sub>inv</sub>-to-IAK ratio. The value of  $P < 0.05$  was considered as statistically significant. All statistical analyses were performed using SPSS software version 20.0 (IBM Corp., Armonk, New York, USA).

### Results

Figure 2 shows the CD curves in constant radiation parameters (60 kVp, 20 mAs) for the seven digital radiography systems. Because different digital radiography systems had different performance in terms of detail (diameter) at different levels of the contrast (depth), the following diagram does not definitely indicate which system has a better performance.

In Figure 3, the ratios of IQF<sub>inv</sub> to IAK for the seven X-ray units in constant radiation parameter (60 kVp, 20 mAs) are shown. One-way ANOVA showed a statistically significant difference in the IQF<sub>inv</sub>-to-IAK ratio between all the seven digital radiography systems ( $P < 0.05$ ). Except for systems of 2 and 4 with similar performance ( $P = 0.105$ ), the five remaining systems had different efficiency ( $P < 0.05$ ). A digital radiography system with a higher IQF<sub>inv</sub>-to-IAK ratio is associated with lower patient dose and better image quality. According to Figure 3, the highest performance in terms of producing high-quality images and low radiation dose is related to X-ray unit 1 (IQF<sub>inv</sub>-to-IAK ratio: 0.00768) and the lowest performance is for X-ray unit 5 (IQF<sub>inv</sub>-to-IAK ratio: 0.005145).

### Discussion

Different digital radiography systems have different efficiencies in terms of the trade-off between image quality

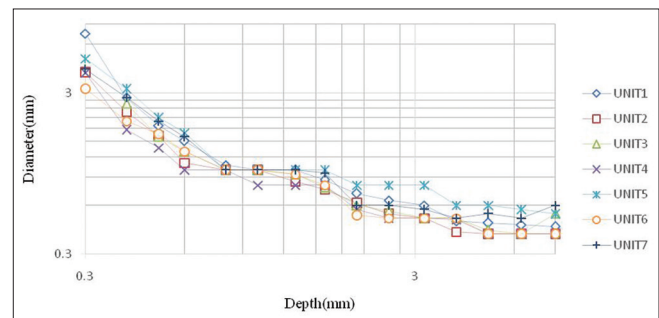
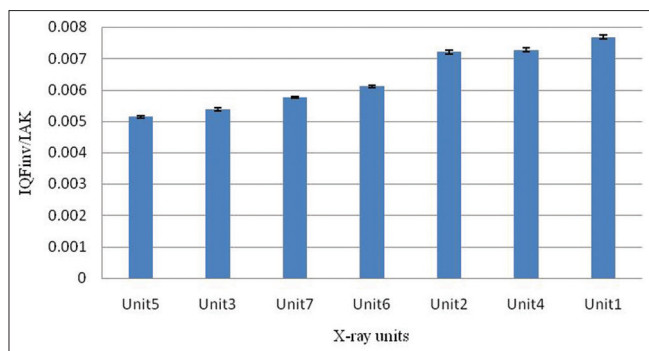


Figure 2: Contrast-detail curves of the seven digital radiography systems in constant radiation parameter (60 kVp, 20 mAs)





**Figure 3: Average inverse image quality figure to incident air kerma ratio for the seven different digital radiography systems**

and radiation dose. In this study, the performances of the seven digital radiography systems were compared in terms of radiation dosage and the quality of the images. The use of the IQFInv-to-IAK ratio for evaluating the performance of digital radiography systems was an innovation in this study.

In the present study, similar to the previous studies,<sup>[15,16]</sup> the CD curves were obtained for comparison of image quality in different radiography systems. However, images were acquired in a constant radiation condition (kVp and mAs) instead of a fixed dose. The reason for using constant conditions was that for a constant radiation dose across all X-ray units, it was impossible to acquire the given radiation conditions (kVp, mAs) among the common stations. In addition, due to the focal spot “blooming” and “thinning” effects, if the selected radiation conditions are not the same in all X-ray units, the focal point size will be different. Focal spot “blooming” is an increase in the focal spot size due to increasing the mA, and focal spot “thinning” is a decrease in the focal spot size due to increasing the kVp. The “blooming” and “thinning” effects are caused by the increasing and decreasing of electron spreading in the electron beam between the cathode and anode in the X-ray tube, respectively. The focal spot size plays an important role in spatial resolution in radiography. As a result of increase in mA and decrease in kVp, the focal spot size will increase, which reduces spatial resolution (detail) and vice versa.<sup>[4]</sup> Therefore, in this study, using fixed radiation conditions, instead of constant radiation dose, the factors affecting the image quality were restricted.

The CD curves cannot be a suitable criterion for comparison of the digital radiography system performance. As shown in Figure 2, in some situations, the CD curves had overlaps and could not definitely indicate which system had a better performance. In addition, another disadvantage of these curves is that they do not give a numerical expression of image quality.<sup>[17]</sup> For these reasons, IQFInv was used to survey the performance of different digital radiography systems, as used by other researchers too.<sup>[15,19,20]</sup> The difference between the present study and other studies was that, instead of comparing the IQFInv values in a stable

dose, IQFInv-to-IAK ratios [Figure 3] were used in a fixed radiation condition. In fact, using these ratios would reduce the factors affecting the image quality and make a more accurate comparison of different digital radiography systems.

A limitation of our study is that there were various factors controlling the quality of images in digital radiography systems. In other words, the difference in radiation dosage not only leads to a difference in image quality but also factors such as type of image receiver, size of focal spot, and image postprocessing are important. In the present study, some attempts were made to control and restrict the confusing factors as much as possible, using constant radiation conditions instead of fixed radiation dose as well as preventing observers from changing the contrast and brightness levels of images.

## Conclusion

In this study, the ratio of IQFInv to IAK was first introduced for comparison of different digital radiography systems. Each system with a higher IQFInv-to-IAK ratio is associated with lower patient dose and better image quality. The results of this study showed that the Arcoma digital radiography system (X-ray unit 1) had a significantly better performance than other X-ray units in terms of image quality and radiation dose. Therefore, it is recommended to equip the new imaging centers with the systems that have higher IQFInv-to-IAK ratios.

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## Conflicts of interest

There are no conflicts of interest.

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