Volume 19, No 2 | International Journal of Radiation Research, April 2021

Independent evaluation and comparison of digital radiography image quality in nine major imaging centers affiliated to Shiraz University of Medical Sciences

M.A. Mosleh-Shirazi[1,2], M. Amiri[3,4*], R. Ravanfar Haghighi[5*], M. Mahdavi[1,3], F. Zarei[5,6]

[1]Ionizing and Non-Ionizing Radiation Protection Research Center, School of Paramedical Sciences, Shiraz University of Medical Sciences, Shiraz, Iran.
[2]Department of Radio-oncology, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Department of Radiology, School of Paramedical Sciences, Shiraz University of Medical Sciences, Shiraz, Iran
[4]Student Research Committee, Shiraz University of Medical Sciences, Shiraz, Iran
[5]Medical Imaging Research Center, Shiraz University of Medical Sciences, Shiraz, Iran
[6]Department of Radiology, School of Medicine, Shiraz University of Medical Sciences, Shiraz, Iran

► ***Original article***

***Corresponding authors:**
Rezvan R. Haghighi, PhD.,
E-mail:
ravanhaghighi@yahoo.com
Mozhdeh Amiri, M.Sc.
E-mail:
mozhdehamiri128@gmail.com

Revised: March 2020
Accepted: April 2020
Int. J. Radiat. Res., April 2021; 19(2): 269-279
DOI: 10.29252/ijrr.19.2.269

ABSTRACT

Background*:** To audit image quality (IQ) of computed radiography (CR), indirect digital radiography (IDR) and direct digital radiography (DDR) systems used in nine centers affiliated to Shiraz University of Medical Sciences, Shiraz, Iran. ***Material And Methods: Sixteen imaging units (four CR, five IDR and seven DDR) employing 26 image receptors were assessed. After ensuring the accuracy of X-ray generator performance, IQ was evaluated using a contrast-detail phantom. Spatial resolution, low contrast detectability (LCD) and dynamic range (as subjective indicators) and contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) (as objective quantities) were evaluated. Further, the IQ evaluators of different image receptor types were compared. ***Results*:** One CR unit failed the X-ray generator performance tests and was excluded from the rest of the study. All 25 remaining image receptors passed the LCD, CNR and SNR criteria. Contrast dynamic range failed in 19 receptors, 17 of them being within a 'borderline' failure range. Spatial resolution failed in 18 detectors; 12 of them were borderline failures. The IDR units performed better than the CR and DDR detectors in terms of LCD (p=0.012) and SNR (p=0.007). ***Conclusions*:** All of the evaluated receptors passed the majority the IQ tests (both physical indicators and one out of the three subjective ones), while contrast dynamic range and spatial resolution of the majority of the failed detectors were borderline failures. Significant differences were observed in IQ among the three image receptors types. The results suggest the need for an improved maintenance, quality assurance and audit program.

***Keywords*:** *Quality assurance health care, quality control, digital radiography, signal detection psychological, diagnostic X-ray radiology.*

[DOI: 10.52547/ijrr.19.2.4]

INTRODUCTION

In the past two decades, the use of digital radiography, i.e., computed radiography (CR) and full-field digital-radiography (DR), has grown rapidly (1, 2). The main difference between these systems and analogue devices is in the image receptor structure and characteristics (3). Digital image receptors have key advantages including potentially higher overall image quality (IQ). A common perception used to be that better IQ could be obtained with a lower dose in any digital system, but the reality has been shown to be quite different. Depending on detector type, some digital systems may have low efficiency, even lower than screen-film systems (4, 5).

Radiographic imaging represents the largest source of man-made radiation exposure to the population (6). Quality assessment in diagnostic radiography, however, is not always adequate (1). For many years, diagnostic radiography involved equipment with relatively low complexity and, therefore, quality assurance (QA) was regarded as rather unnecessary except at the installation or service times. As equipment complexity has increased rapidly, the need for accurate diagnosis while limiting patient dose has substantially expanded the requirements for QA (1). Quality control (QC) tests are done to ensure the constancy of performance in digital systems. Furthermore, a QA program is a prerequisite for determination of dose or diagnostic reference level and optimization studies (7-9).

IQ is determined in terms of image resolution, subject contrast, image noise, contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR), etc. (4, 10, 11). IQ evaluation methods are more complex than dose assessment approaches (12). The use of contrast-detail phantom analysis is typical in IQ assessment (13). Many studies have evaluated and compared the IQ of different imaging systems, performed by subjective (qualitative) and/or objective (quantitative) tests (2, 7, 9, 14-16). Patient dose has been shown to be significantly reduced after such standard IQ assessments (17, 18).

Although studies have shown that, overall, digital imaging systems produce higher quality images compared to analogue systems, due to the large variety of digital systems, the question as to which type of digital systems, i.e., CR, IDR, or DDR, performs best in different imaging tasks is still not answered clearly (8). A comparison of the IQ produced by these systems after a few years of routine clinical use is of particular interest.

Auditing is a recommended and important part of a QA program. Further, it has been emphasized to replace internal audits with independent and unbiased external auditors (1, 19). Auditing goes beyond what an imaging center should do routinely, by independently performing a common and uniform assessment across all the audited centers. The QA that a center carries out routinely should help the center to pass the audit. The audit effectively checks and asks whether the required QA has been done (or performed sufficiently well).

Since QA in terms of IQ has not been performed so far in a systematic way across the hospitals affiliated to Shiraz University of Medical Sciences, the first aim of this study was to evaluate the IQ of DR systems in nine major diagnostic centers using a contrast-detail phantom according to the recommendations of the American Association of Physicists in Medicine (20, 21). The second aim was to compare the IQ of the different types of DR systems in routine use to find out any differences between their performances. As subjective and objective methods of IQ evaluations have disadvantages as well as advantages (7, 12, 14, 17, 18, 22), we used a combination of both methods to assess the existing systems. To ensure independence, this audit was carried out by qualified investigators from outside the diagnostic departments in question. The objectives of this study, however, did not include improving image quality or carrying out dose optimization at this stage.

MATERIALS AND METHODS

Sixteen imaging units including 26 image receptors (floor- and/or wall-mounted) in nine high-workload centers affiliated to Shiraz University of Medical Sciences, were assessed. Four CR, five IDR and seven DDR units were evaluated. Various information on the units is shown in table 1. We designated the 16 studied units by letters A to P.

The CR plates were made of photo-stimulable phosphor. Based on the conversion of X-rays to electrical signals through direct or indirect methods, digital detectors are divided into DDR and IDR. The IDR units in this study used cesium iodide (CsI) scintillators to convert X-ray energy into light and amorphous silicon (a-si) to convert light into electrical signal. The direct

[DOI: 10.52547/ijrr.19.2.4]

digital detector were made of amorphous selenium (a-Se) to convert X-ray photon energy directly into electrical signal [22, 23].

To be certain about the performance of the X-ray generators, we checked their tube voltage, exposure time accuracy and mAs linearity as well as carrying out various reproducibility tests (kVp, dose, time) using a semiconductor dosimeter (Black Piranha, RTI, Sweden) following the related protocol [24]. Furthermore, for all units, the air kerma on the image receptor (K_b) was measured at a 100 cm distance from the focal spot. The acceptance level used for variations in kVp and mAs was ±5% [20, 25].

Table 1. Description of the 16 digital radiography systems entered into this study. F: floor-mounted; W: wall-mounted; C: cassette.

Center	Unit	X-ray system	Image receptor type	Detector brand	Detector material	Detector mounting	Detector size (cm)	Detector age (years)
1	A	PAYAMED	IDR	TRIXEL	CsI:Tl a-Si:H	F & W	43 × 43	2
	B	TOSHIBA	CR	FUJI	BaFBr:Eu	C	35 × 43	9
	C	MEHRAN TEB	DDR	DRTEC	a-Se	F & W	43 × 43	5
2	D	PAYAMED	IDR	TRIXEL	CsI:Tl a-Si:H	F & W	43 × 43	3
	E	MEHRAN TEB	DDR	DRTEC	a-Se	F & W	43 × 43	6
3	F	ARYAN DARMAN PAZHUH	IDR	PERKIN	CsI:Tl a-Si:H	F & W	43 × 43	1
	G	MEHRAN TEB	DDR	DRTEC	a-Se	F & W	43 × 43	5
	H	TOSHIBA	CR	AGFA	BaFBr:Eu	C	35 × 43	9
4	I	MEHRAN TEB	DDR	DRTEC	a-Se	F & W	43 × 43	6
	J	MEHRAN TEB	DDR	DRTEC	a-Se	F & W	43 × 43	5
5	K	MEHRAN TEB	DDR	DRTEC	a-Se	W	43 × 43	9
	L	MEHRAN TEB	DDR	DRTEC	a-Se	F & W	43 × 43	6
6	M	MEHRAN TEB	IDR	VAREX	CsI:Tl a-Si:H	F	43 × 43	1
7	N	INOMED	CR	FUJI	BaFBr:Eu	C	35 × 43	5
8	O	MEHRAN TEB	IDR	VAREX	CsI:Tl a-Si:H	F & W	43 × 43	1
9	P	PHILIPS	CR	KONICA	BaFBr:Eu	C	35 × 43	6

Contrast-detail phantom

A DIGRAD A+K phantom (Pehamed, Germany) was used to evaluate the IQ of the imaging systems (figure 1). We used its field markings to check the correspondence between light and X-ray fields, the six low-contrast objects for the evaluation of low-contrast detectability (LCD), the copper seven-step wedge for determination of dynamic range and the high-contrast lead bar pattern for the spatial resolution.

As the phantom had been manufactured to correspond to the DIN 6868/58 protocol [26], we used the acceptance criteria stated in that reference. The maximum acceptable limit used for light/X-ray field coincidence was 2% of the source to image distance (SID) (i.e., 2 cm for the SID of 100 cm). The other acceptance levels were as follows. Low-contrast test: at least three low-contrast elements should be visible; Contrast dynamic range: all seven step-wedges should be resolved; Spatial resolution: tolerance of 2.4 line pairs per millimeter (lp/mm) for $K_b \leq 5$ μGy (K_b was less than 5μGy for all of the receptors in this study).

[DOI: 10.52547/ijrr.19.2.4]

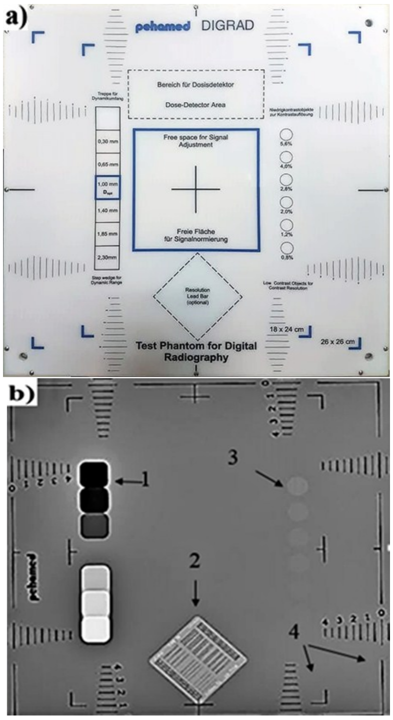

Figure 1. a) The DIGRAD A + K digital radiography phantom used in this study; **b)** Radiographic image of the phantom. Different parts of the phantom: (1) contrast dynamic range, (2) spatial resolution, (3) LCD, (4) field marking.

Image acquisition

The phantom was placed below the X-ray tube on the table for floor-mounted units or fixed onto wall-mounted detectors using a custom-made holder. The longitudinal axis of the X-ray tube was perpendicular to the step-wedge direction to avoid the heel effect and accurately measure contrast dynamic range. For each X-ray system, the images were acquired in two different field sizes with the same exposure parameters. Field sizes of 18×24 cm and 24×24 cm were used for small and large field size evaluation, respectively. The images were taken using fixed parameters: 100 cm focus to detector distance, 80 kVp and 10 mAs tube settings for all units and their related detectors. The images were saved in DICOM format without post-processing.

To estimate the dose delivered to obtain each image, the radiation output (dose to air) was measured for the above-mentioned parameters using a multi-function meter with a semiconductor detector (Black Piranha, RTI, Sweden).

Subjective assessment of image quality

The images were displayed on a Barco monitor (MDMC- 12133, Belgium). The light of the reading room was kept below 50 lx and the observers allowed 5 min before image evaluation for dark adaptation (27). Three expert radiology technologists with a minimum of 5 years' experience were asked to independently evaluate LCD, spatial resolution and contrast dynamic range as blinded observers. One observer repeated the experiment four weeks later for evaluation of intra-observer variability. The observers filled out forms by giving scores to each IQ evaluator. The average scores from the observers were calculated and used in this study.

Objective assessment of image quality

As quantitative, objective evaluators of IQ, CNR and SNR were calculated by selecting suitable-sized regions of interest (ROIs) in the background and lowest contrast regions of the phantom images. The INFINITT PACS software (Seoul, South Korea) was used for this purpose. A fixed ROI size (38 mm^2) on the same region of the images was used to measure the mean pixel values and the related standard deviations of the signal and background regions. The mean pixel value of the lowest contrast of phantom image was considered as signal, and noise was calculated from the standard deviation (σ) of the background. Therefore, CNR was calculated as the ratio of the differences between mean pixel values of the signal (S) and background (B), divided by the noise value ($CNR=S-B/\sigma_B$). SNR was computed as the ratio of the mean pixel value of ROI signal and noise (standard deviation of background) ($SNR=S/\sigma_B$). This is considered as a direct method of measuring SNR. The minimum threshold levels of 2.5 and 5 were considered for CNR and SNR, respectively (3).

Statistical analysis

The Kohen kappa (κ) test was used to determine the level of agreement between intra-observer and inter-observer data. A κ value was quantified in pairs for the three observers. A κ value greater than 0.4 and 0.6 represented *moderate* (clinically acceptable) and

[DOI: 10.52547/ijrr.19.2.4]

good agreement, respectively, and a value below 0.4 was considered as *fair* agreement. The *Mann-Whitney* U *test was used for testing significant differences in LCD, contrast dynamic range, spatial resolution, CNR and SNR between floor- and wall-mounted IDR/DDR detectors. The* Kruskal-Wallis H test was used for testing significance in differences among the three different image receptors type *in terms of LCD, contrast dynamic range, spatial resolution, CNR and SNR*.

RESULTS

X-ray generator performance

The X-ray generator QC tests showed that thirteen out of the 16 evaluated units passed all the tests (table 2). Two of the failures (units *H* and *K*) involved time (unit H) and kVp inaccuracy (unit K), were repaired by engineers. The time and kVp accuracy tests were repeated on these units, which showed that the issues were resolved. The third failed machine (unit *P*), did not pass any of the tests except kVp reproducibility, and was, therefore, excluded from the rest of the study and, subsequently, taken out of clinical service. Linearity of the mAs was observed in all units ($r^2 = 1.00$).

Radiation dose

Minimum, maximum and mean measured radiation output (dose to air) for the most commonly used exposure factors were 0.3 mGy, 0.8 mGy and 0.5 mGy, respectively. The calculated standard deviation was 0.1 mGy.

Light/X-ray field coincidence

The light/X-ray field coincidence tests showed that in three units (*E, I, P*) out of the 16, deviations were > 2 cm (2% error) (3.5, 3.0 and 4.0 cm, respectively). Two units were repaired successfully, while work to fix this issue in unit *I* is ongoing.

Subjective image quality

All of the systems passed the LCD test by detecting at least four low contrast objects out of six (figure 2). The error bars in this and other figures represent one standard deviation.

The contrast dynamic range test was acceptable (by resolving all 7 steps) in 6 image receptors out of 25 (figure 3). Nineteen receptors failed; 17 of them were within a narrow 'borderline' failure range defined by the authors as being between 6 and 7 steps. The other two units could only resolve 5 steps.

High contrast spatial resolution in 7 detectors was higher than the acceptance level of 2.4 lp/mm, while in 18 receptors, it was lower (figure 4). Again, we defined a borderline failure range (2.0-2.4 lp/mm), which encompassed 12 out of the 18 failed detectors.

The results of the intra- and inter-observer studies, to assess the subjective image quality, were as follows. A κ-value of 0.65 indicated that the intra-observer agreement was good (κ-value>0.6). As for inter-observer variations, κ-values of 0.53, 0.75 and 0.68 in each pair among the three observers were indicative of moderate (κ-value>0.4) and good agreement, respectively.

CNR and SNR

As presented in figures 5 and 6, the calculated CNR and SNR in all systems were much higher than the typical CNR criteria of 2.5 and the theoretical minimum SNR of 5. The minimum observed values of CNR and SNR were 31 and 37, respectively (both belonged to CR receptors). The highest values of CNR and SNR found were 248 (floor-mounted IDR) and 232 (DDR), respectively.

Comparison of image quality among different detector types

For both IDR and DDR units, the differences in the mean values of each test result in the same receptor types between floor- and wall-mounted detectors were statistically insignificant for all IQ evaluators: LCD (p=0.899 and 0.554), dynamic range (*p*=0.055 and 0.542), spatial resolution (p=0.243 and 0.151), CNR (p=0.623 and 0.886), and SNR (p=0.624 and 0.351), for IDR and DDR, respectively. We, therefore, averaged the values of floor- and wall-mounted detectors in each detector type when

[DOI: 10.52547/ijrr.19.2.4]

comparing IQ among the three receptor types.

Figure 7 shows a comparison of the three receptor types in terms of LCD and contrast dynamic range. Significant differences in LCD were observed between the IDR and CR detectors (p=0.012), whereas DDR units were not significantly different from the other two. For dynamic range, although some differences among the CR, IDR and DDR detectors were observed, they were not statistically significant (p= 0.067). On the other hand, for spatial resolution (figure 8), significant differences were observed between the IDR and DDR units and also between DDR and CR detectors (p = 0.001). Similarly, the differences in SNR between the IDR and CR detectors were significant (*p* = 0.007), but not CNR (p = 0.05) (figure 9).

Table 2. Results of the X-ray generator performance assessment and their corresponding tolerance limits.

Units	kVp accuracy (max. inaccuracy) (%)	Reproducibility (%)			Time accuracy (max. inaccuracy) (%)
	(Limit: -5% to 5%)	kVp (Limit: 10%)	dose (Limit: 10%)	time (Limit: 10%)	(Limit -10% to 10%)
A	1	1	0.2	1.4	-4.4
B	-2.9	0.1	0.1	0.9	-8.8
C	-2.9	0.1	0.1	1.1	10.0
D	-1.5	0.1	0.6	4.9	10.4
E	3	0.1	0.1	6.0	-1.7
F	-0.8	0.1	0.1	1.4	-1.8
G	1.3	0.1	0.1	0.0	-1.6%
H	-2.6	0.1	0.1	0.3	-48.4 (-6.7)^a
I	-3.6	0.1	0.2	0.8	-9.6
J	-4.3	0.1	0.3	0.3	-8.3
K	-6.1 (1.5)^a	0.1	0.3	0.1	1.8
L	-4.3	0.0	0.0	0.4	7.3
M	-0.7	0.1	0.1	1.3	9.8
N	4.1	0.1	0.1	1.0	9.85
O	-3.7	0.1	0.2	1.0	9.8
P*	18.5	0.3	12.4	11.0	82.5

a Values after reporting and repair.

* This unit failed all tests except kVp reproducibility and was excluded from the study.

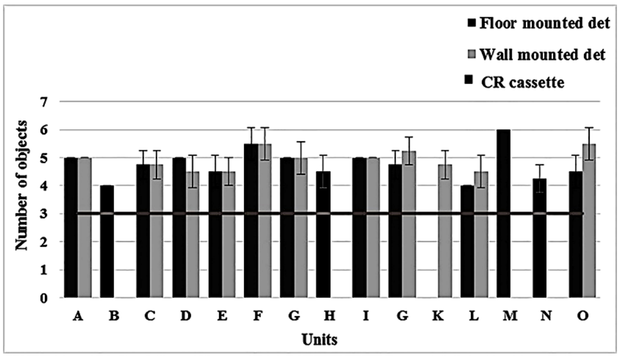

Figure 2. LCD for the 25 image receptors in the 15 assessed digital radiography units in terms of the mean number of low-contrast objects out of 6, resolved by the observers for each unit. The horizontal line represents the acceptance level.

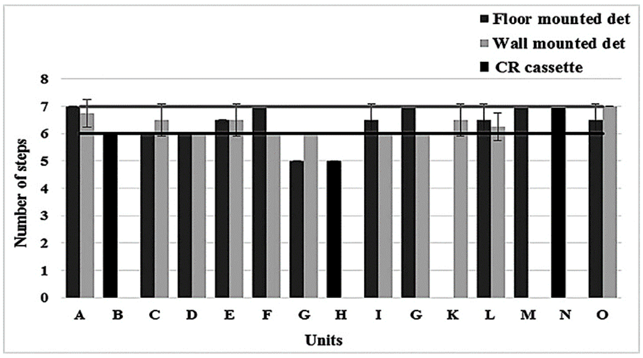

Figure 3. Contrast dynamic range for the 25 image receptors in the 15 assessed digital radiography units, in terms of the mean number of steps out of 7, resolved by the observers for each unit. The upper horizontal line represents the acceptance level. The lower bound of the borderline range is shown by the lower horizontal line.

[DOI: 10.52547/ijrr.19.2.4]

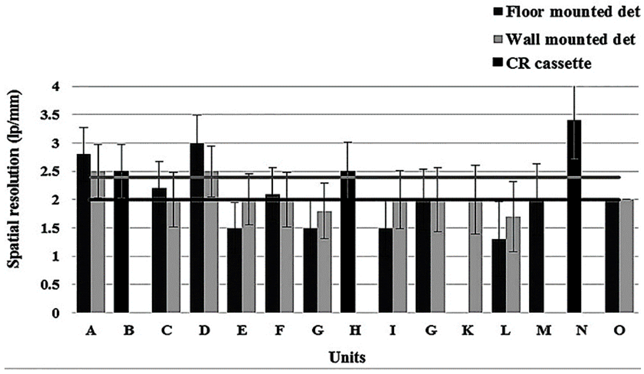

Figure 4. Spatial resolution of the 25 image receptors in the 15 assessed digital radiography units. The upper horizontal line represents the acceptance level. The lower bound of the borderline range is shown by the lower horizontal line.

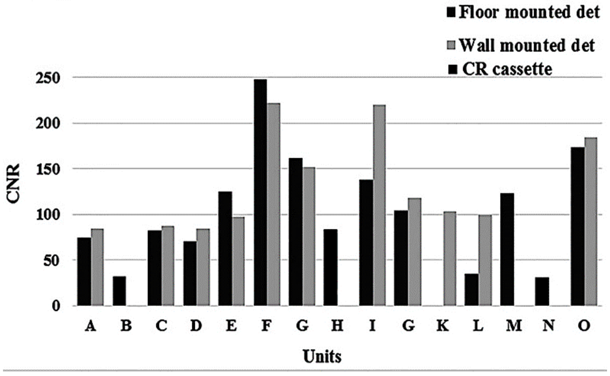

Figure 5. CNR of the 25 image receptors in the 15 assessed digital radiography units.

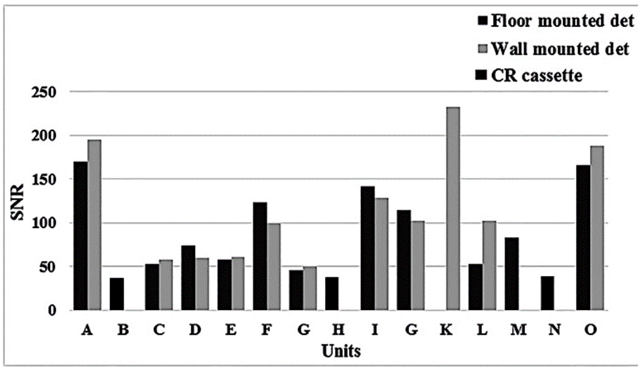

Figure 6. SNR of the 25 image receptors in the 15 assessed digital radiography units.

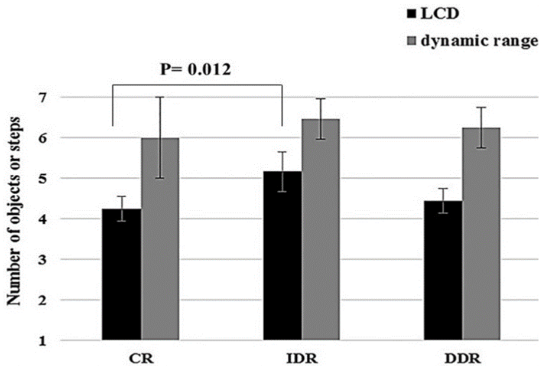

Figure 7. Average values of LCD and contrast dynamic range in three different image receptors.

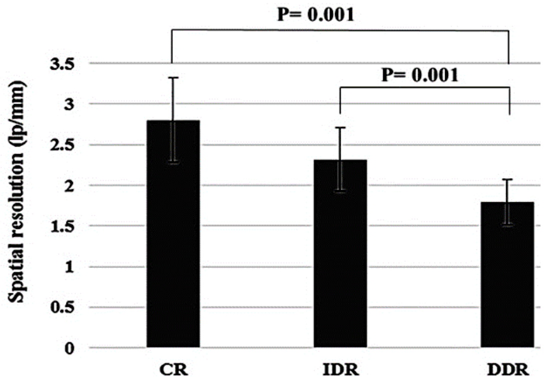

Figure 8. Average values of spatial resolution specified as lines pair per millimeter in CR, DDR and IDR image receptors.

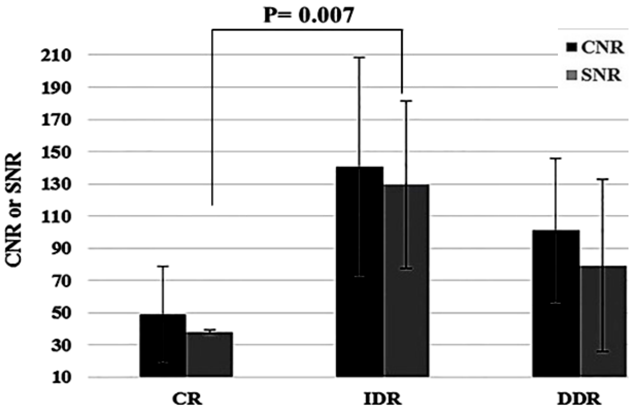

Figure 9. Average values of CNR or SNR in three different image receptors (CR, IDR and DDR).

DISCUSSION

The main purpose of this study was to audit the digital radiography units employed in nine large and busy imaging departments. After ensuring an acceptable performance of the X-ray generators, the IQ of the existing CR, IDR and DDR units were assessed using psychophysical and objective methods, based on recommended standards. Then, IQ was compared on the basis of the type of image receptor.

Variation in kVp (acceptable limits for

[DOI: 10.52547/ijrr.19.2.4]

accuracy ±5% and reproducibility ±10%), exposure time (acceptable limits for accuracy and reproducibility ±10%), and mAs linearity represent the performance of the x-ray generator, which ultimately affect IQ. The tests were repeated and passed in the two units that failed the kVp and time accuracy after repair but one unit was excluded from the rest of the study because it was not repairable. Coincidence of X-ray/light was not acceptable in three of the systems, caused by displacement of the optical system after repairing the X-ray tube or replacement of the light bulb.

Surveying the IQ of the imaging units showed that most of them had sufficient IQ. The objective tests, and one out of the three subjective ones (LCD), were passed by all of the evaluated receptors. The large majority of the failed detectors in terms of contrast dynamic range and spatial resolution fell into narrow 'borderline failure' ranges. As for the comparison of IQ among the three receptor types (CR, IDR, DDR), there was a statistically significant difference between CR and IDR, while the performance level of the DDR systems was often between those two.

A previous study of IQ evaluation in Iran was performed in Tabriz, where 11 DR units (8 DDR and 3 CR) were evaluated. Three spatial resolution and one contrast dynamic range tests failed, while all units passed the LCD test (15). The number of the evaluated units was fewer than our audit and only subjective IQ tests were performed in that study. The types of failed tests in that study were the same as our audit, while lower proportions of their units failed compared to our study. An audit carried out in western Croatia included 17 radiography units. The results of X-ray generator and field coincidence assessment tests were comparable with our study, while both IQ tests (spatial resolution and low-contrast resolution) using a Flu/Rad phantom were passed by all units (9). In another study, 14 DDR units in Italy were evaluated using only physical parameters, namely, modulation transfer function (MTF), noise power spectrum and detective quantum efficiency (DQE). All of the units passed the tests (28). All of the units in our audit passed the LCD test. LCD is one of the main properties in a radiograph (16). Desirable contrast resolution leads to increased detection of differences, especially in anatomical regions with low intrinsic contrast (15).

The assessment of dynamic range and high-contrast spatial resolution highlighted the main shortcomings in the audited units. In comparison to most previous studies, failures in these two tests were observed in larger proportions of the units, albeit mostly borderline failures (19). Dynamic range degradation deteriorates contrast resolution. Large failures in the dynamic range test were observed in two detectors (one CR, one DDR). The reason may stem mainly from the intrinsic characteristics of the detector and the display system. Spatial resolution of four DDR and two IDR detectors failed with fairly large deviations from the acceptable level, while the best spatial resolution (3.4 lp/mm) belonged to a CR detector. Spatial resolution of CR systems is a function of the characteristics of their laser beam, such as the diameter in the readout portion of the reader system. Spatial resolution of DR systems depends on detector material, thickness and pixel size (13, 18, 23, 29).

Qualitative evaluation of IQ, using human observer interpretation, is very difficult and cannot be used for calibration (30). To perform assessments in a more quantitative, robust and global way, a number of objective quantities have been developed. Image signal and noise are identified as basic components of IQ. In particular, noise analysis is very important. Image noise affects LCD and deteriorates diagnostic IQ (10). Thus, in this study, objective evaluators (CNR and SNR) were also calculated (30). The efficiency of optical photon production and coupling in IDR detectors are also factors affecting their SNR and CNR (31, 32). The lowest calculated CNR was 31. Measurement-derived values of CNR may depend on the test object. Furthermore, image contrast in digital imaging systems can be manipulated. Therefore, SNR values were also calculated (7, 29). We used a fixed ROI size to prevent the effects of ROI size variations on the minimum SNR and nonuniformity metrics (7). The calculated SNRs

[DOI: 10.52547/ijrr.19.2.4]

and CNRs were in good agreement. The CNR and SNR results provided a more complete picture for the assessment of the LCD of the audited systems.

Our study showed that in some systems, in spite of using similar image receptors (material, model and manufacturer), IQs were different. This issue has been previously reported and attributed to differences in X-ray system, software processing, age or frequency of detector usage (14). We also found that the IQ differences between some floor- and wall-mounted detectors belonging to the same unit were related to how frequent each detector was used.

Many studies have evaluated IQ of different imaging systems. Some have used qualitative methods, such as receiver operating characteristic and visual grading analysis. Such methods require a large number of images and, therefore, are difficult and time consuming (12, 33, 34). Other studies have used solely quantitative evaluators such as MTF, DQE, CNR and SNR (8, 11, 14). To carry out a more complete evaluation (35), we used both subjective and objective methods. The second part of the study, i.e., comparison of the IQ of the different types of digital detectors in use in the nine centers, showed some differences among them. These variations were mainly due to the differences between the types and/or age of image receptors. The results showed that, on average, IQ of the IDR detectors was higher than the other two types (CR and DDR). IQ of DDR detectors ranked second and CR showed the lowest overall IQ. This result is in line with previous studies, which revealed that IQ in CR was lower than IDR and DDR (16, 35-39). The low IQ in CR can be explained by the lower absorption and conversion coefficient efficiency, higher noise due to plate granularity and readout noise (16, 36, 37). On the other hand, some studies showed that IQ in CR is comparable to, or higher than, IDR detectors. IQ in CR has been shown to be higher for low (≤55) kVp. In contrast, IQ in DR increases with increasing kVp (11, 40).

The IDR detectors exhibited the highest level of IQ in all tests, except for spatial resolution, while the spatial resolution in CR was better than IDR and DDR (although the difference between CR and IDR was not statistically significant). This can be explained by the higher DQE of CR plates (that include Ba with Z=56) than that of DDR (made of selenium with Z=34). The IDR receptors include CsI (Z_{Cs}=55, Z_I=53), i.e., close to CR plates. Therefore, DQE was higher for CR although without statistical significance. Some previous studies showed a lower spatial resolution in CR compared to the two other types (15, 18). Spatial resolution is influenced by pixel size, blur and other factors (41). Higher spatial resolution in CR was, however, at the expense of lower contrast detectability.

As a strong point of the present work, we can point out the use of a combination of both subjective and objective methods due to their complementary information and advantages. Also, a relatively large number of image receptors from various manufactures were audited. Moreover, introduction of a borderline failure category (instead of a simple, binary, pass/fail approach) allowed us to highlight a sizeable number of units that closely failed the QC tests, which can be useful for policymaking. Finally, moderate to good levels of intra- and inter-observer reproducibility were achieved in the subjective tests, as well as reasonable reproducibility in the objective CNR and SNR tests (partly due to using a fixed-size ROI). On the other hand, this audit would have benefitted from inclusion of a larger number of observers in the subjective tests, which was not practicable. Also, we compared the IQ of detectors with various histories of clinical use in terms of both frequency and length of time, so the comparison is only indicative of the present status of the units in use in the audited centers. However, this approach is informative too by providing data on the durability of the imaging systems under heavy clinical use in busy departments. The mean age of the IDR detectors (1.6 year) was substantially lower than the DDR units (6 years). The lower IQ in this type of detector may at least be partly due to higher saturation by frequent exposures over time.

This type of study can help by highlighting existing maintenance and QA problems in

[DOI: 10.52547/ijrr.19.2.4]

[DOI: 10.52547/ijrr.19.2.4]

imaging departments (17). The problems seen in the centers in some low- and middle-income countries may be attributed to inadequate supervision stemming from a shortage of expert medical physicists and insufficient QC tools (1, 9). For systems that lack X-ray generator acceptance and commissioning tests, the results of this study may be used to establish baseline values for future QC checks.

Independent audit has an important role in maintaining quality and IQ assessment is one of the main aspects of QA, with the goal of achieving accurate diagnosis together with reduced patient dose. Improved assessment of the IQ of DR systems through the establishment of a comprehensive QA program is suggested. To that end and to follow the *As Low As Reasonably Achievable (ALARA)* principle, an optimization study is being carried out by the authors to identify the most suitable exposure factors that offer acceptable diagnostic IQ with lowest patient dose.

CONCLUSIONS

The results suggest that IQ in the majority of the audited DR units is acceptable or close to the acceptance level. All of the evaluated receptors passed the majority the tests (both physical indicators and one out of the three subjective ones), while contrast dynamic range and spatial resolution of the majority of the failed detectors were borderline failures. Significant IQ differences were observed among the imaging units as a whole, as well as between the different detector types. These findings can be used for dose optimization and as a reference values for future QC. The relatively high number of borderline cases in some IQ tests presents an opportunity for improvement through better maintenance and QA. An IQ optimization project is underway at these centers.

ACKNOWLEDGEMENTS

This article is extracted from a postgraduate thesis by Mrs. M. Amiri, funded by Shiraz University of Medical Sciences, Shiraz, Iran (project number 97-01-10-17420). The authors would like to sincerely thank the management and staff at the imaging centers participating in this study and Mr. Mohammad Ali Golkari for his kind help with some of the experimental measurements. The useful help and information received from the Mehran Teb, Aryan Darman Pazhuh and Payamed companies are gratefully acknowledged.

Conflicts of interest: *Declared none.*

REFERENCES

1. Delis H, Christaki K, Healy B, Loreti G, Poli G, Toroi P, *et al.* (2017) Moving beyond quality control in diagnostic radiology and the role of the clinically qualified medical physicist. *Physica Medica, **41**: 104-8*.
2. Sandborg M, Tingberg A, Ullman G, Dance DR, Alm Carlsson G (2006) Comparison of clinical and physical measures of image quality in chest and pelvis computed radiography at different tube voltages. *Medical physics, **33**(11): 4169-75*.
3. Bushberg JT and Boone JM (2011) The essential physics of medical imaging: Lippincott Williams & Wilkins.
4. Seibert JA (2008) Digital radiography: image quality and radiation dose. *Health physics, **95**(5): 586-98*.
5. Schaefer-Prokop C, Uffmann M (2009) Update on digital radiography. *European journal of radiology, **72**(2): 193*.
6. UNSCEAR. UNSCEAR 2008 Report to the General Assembly, with Scientific annexes. United Nations New York; 2010.
7. Li G, Greene TC, Nishino TK, Willis CE (2016) Evaluation of cassette-based digital radiography detectors using standardized image quality metrics: AAPM TG-150 Draft Image Detector Tests. *Journal of applied clinical Medical Physics. **17**(5): 391-417*.
8. Lee KL, Bernardo M, Ireland TA (2016) Benchmarking the performance of fixed-image receptor digital radiography systems. Part 2: system performance metric. *Australasian Physical & Engineering Sciences in Medicine, **39**(2): 463-76*.
9. Šegota D, Diklić A, Jurković S (2018) Implementation of quality assurance program in radiography—2-year experience of collaboration with public health institutions in west region of Croatia. *Radiation Protection Dosimetry, **182**(3): 329-34*.
10. Ergun L and Olgar T (2017) Investigation of noise sources for digital radiography systems. *Radiological Physics and Technology, **10**(2): 171-9*.
11. McEntee M, Frawley H, Brennan PC (2007) A comparison of low contrast performance for amorphous Silicon/caesium iodide direct radiography with a computed radi-

ography: a contrast detail phantom study. *Radiography,* ***13*** *(2): 89-94*.

12. Al-Murshedi S, Hogg P, England A (2018) An investigation into the validity of utilising the CDRAD 2.0 phantom for optimisation studies in digital radiography. *The British Journal of Radiology,* ***91****(1089): 20180317*.
13. Uffmann M, Schaefer-Prokop C (2009) Digital radiography: the balance between image quality and required radiation dose. *European Journal of Radiology,* ***72****(2): 202-8*.
14. Aksoy ME, Kamasak ME, Akkur E, Ucgul A, Basak M, Alaca H (2012) Evaluation and comparison of image quality for indirect flat panel systems with CsI and GOS scintillators. 2012 7th International Symposium on Health Informatics and Bioinformatics; 2012: IEEE.
15. Gharehaghaji N, Khezerloo D, Abbasiazar T (2019) Image quality assessment of the digital radiography units in Tabriz, Iran: A phantom study. *Journal of Medical Signals & Sensors,* ***9****(2): 137*.
16. Al-Murshedi S, Hogg P, Lanca L, England A (2018) A novel method for comparing radiation dose and image quality, between and within different x-ray units in a series of hospitals. *Journal of Radiological Protection,* ***38****(4): 1344*.
17. Kloth JK, Neumann R, von Stillfried E, Stiller W, Burkholder I, Kauczor H-U, *et al.* (2016) Quality-controlled dose-reduction of pelvic X-ray examinations in infants with hip dysplasia. *European Journal of Radiology,* ***85****(1): 233-8*.
18. Aldrich JE, Duran E, Dunlop P, Mayo JR (2006) Optimization of dose and image quality for computed radiography and digital radiography. *Journal of Digital Imaging,* ***19*** *(2):126-31*.
19. Qian X (2011) IAEA human health series no. 4, comprehensive clinical audits of diagnostic radiology practices: a tool for quality improvement. LWW; 2011.
20. Jones AK, Heintz P, Geiser W, Goldman L, Jerjian K, Martin M, *et al.* (2015) Ongoing quality control in digital radiography: report of AAPM Imaging Physics Committee Task Group 151. *Medical Physics,* ***42****(11): 6658-70*.
21. Seibert JA, Bogucki TM, Ciona T, Huda W, Karellas A, Mercier J, *et al.* (2006) Acceptance testing and quality control of photostimulable storage phosphor imaging systems. *Rpt of AAPM Task Group. (10)*.
22. Sample B (2012) Best Practices in Digital Radiography.
23. Copple C, Robertson ID, Thrall DE, Samei E (2013) Evaluation of two objective methods to optimize kVp and personnel exposure using a digital indirect flat panel detector and simulated veterinary patients. *Veterinary Radiology & Ultrasound,* ***54****(1): 9-16*.
24. Shepard S, Lin P, Boone J, Cody D, Fisher J, Frey G, *et al.* (2002) AAPM Report No. 74 Quality Control in Diagnostic Radiology. *Report of the Task Group.12*.
25. Boone JM, Cody DD, Fisher JR, Frey GD, Glasser H, Gray JE, *et al.* (2002) Quality control in diagnostic radiology. *New York: Am Asso Med Phys,* ***74****: 1-77*.
26. Schreiner-Karoussou A (2005) Review of image quality standards to control digital X-ray systems. *Radiation protection dosimetry,* ***117****(1-3): 23-5*.
27. Dance D, Christofides S, Maidment A, McLean I, Ng K (2014) Diagnostic radiology physics: A handbook for teachers and students. Endorsed by: American Association of Physicists in Medicine, Asia-Oceania Federation of Organizations for Medical Physics, European Federation of Organisations for Medical Physics. *International Atomic Energy Agency (IAEA): IAEA.*
28. Nitrosi A, Bertolini M, Borasi G, Botti A, Barani A, Rivetti S, *et al.* (2009) Application of QC_DR software for acceptance testing and routine quality control of direct digital radiography systems: Initial experiences using the Italian Association of Physicist in Medicine Quality Control Protocol. *Journal of digital imaging,* ***22****(6): 656*.
29. Schaefer-Prokop C, De Boo D, Uffmann M, Prokop M (2009) DR and CR: Recent advances in technology. *European Journal of Radiology,* ***72****(2): 194-201*.
30. Tapiovaara M and Wagner R (1993) SNR and noise measurements for medical imaging: I. A practical approach based on statistical decision theory. *Physics in Medicine & Biology,* ***38****(1): 71*.
31. Roncali E, Mosleh-Shirazi MA, Badano A (2017) Modelling the transport of optical photons in scintillation detectors for diagnostic and radiotherapy imaging. *Physics in Medicine & Biology.62(20):R207*.
32. Swindell W and Mosleh-Shirazi M (1995) Noise reduction by frame averaging: a numerical simulation for portal imaging systems. *Medical Physics,* ***22****(9): 1405-11*.
33. Redlich U, Hoeschen C, Doehring W (2005) Assessment and optimisation of the image quality of chest-radiography systems. *Radiation Protection Dosimetry,* ***114****(1-3): 264-8*.
34. Yano Y, Yabuuchi H, Tanaka N, Morishita J, Akasaka T, Matsuo Y, *et al.* (2013) Detectability of simulated pulmonary nodules on chest radiographs: comparison between irradiation side sampling indirect flat-panel detector and computed radiography. *European Journal of Radiology,* ***82*** *(11): 2050-4*.
35. Borasi G, Samei E, Bertolini M, Nitrosi A, Tassoni D (2006) Contrast-detail analysis of three flat panel detectors for digital radiography. *Medical Physics,* ***33****(6Part1): 1707-19*.
36. Niimi T, Imai K, Maeda H, Ikeda M (2007) Information loss in visual assessments of medical images. *European Journal of Radiology,* ***61(2)****: 362-6*.
37. De Boo DW, Weber M, Deurloo EE, Streekstra GJ, Freling NJ, Dongelmans DA, et al. (2011) Computed radiography versus mobile direct radiography for bedside chest radiographs: impact of dose on image quality and reader agreement. *Clinical Radiology,* ***66****(9): 826-32*.
38. Cowen A, Kengyelics S, Davies A (2008) Solid-state, flat-panel, digital radiography detectors and their physical imaging characteristics. *Clinical Radiology,* ***63****(5): 487-98*.
39. Bacher K, Smeets P, Vereecken L, De Hauwere A, Duyck P, De Man R, *et al.* (2006) Image quality and radiation dose on digital chest imaging: comparison of amorphous silicon and amorphous selenium flat-panel systems. *American Journal of Roentgenology,* ***187****(3): 630-7*.
40. Sheridan N and McNulty J (2016) Computed radiography versus indirect digital radiography for the detection of glass soft-tissue foreign bodies. *Radiography,* ***22****(3): 223-7*.
41. Bourne R (2010) Fundamentals of digital imaging in medicine: Springer Science & Business Media.

[DOI: 10.52547/ijrr.19.2.4]