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Assessment of Image Quality and Radiation Dose to Adult Patients undergoing Computed Radiography Examinations

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ABSTRACT

Image quality and its related entrance surface dose to adult patients undergoing computed radiography (CR) examinations have been assessed using ImageJ software version 1.48 in two hospitals H-1 and H-2. In all 70 radiographs of adult patients were examined in the study consisting of 10 each for chest PA, cervical spine AP and LAT, lumbar spine AP and LAT and skull AP and LAT. Image quality of the radiographic images was assessed in terms of contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR). The CNR for all examinations were between 3.54 ± 3.27 and 20.63 ± 8.65 for the two hospitals involved in this study. A maximum difference 17.09 in CNR was found between hospital 1 (H-1) and 2 (H-2). The results obtained for SNR for both hospitals showed that 92.86% of all the images assessed were at least 1.22 higher than the Rose Model of the threshold value of ≥ 5. The images were of good quality and hence, they provided useful clinical information. The relationship between CNR and the entrance surface dose (ESD) to patients for all the examinations showed that there is a potential to reduce doses to patients while keeping images of diagnostic quality.

Keywords: Contrast-to-noise ratio (CNR), Signal-to-noise ratio (SNR), Optimisation

I. INTRODUCTION

Image quality assessment still remains a challenge in the field of image processing. It is still not satisfyingly solved and new approaches are still appearing. According to the International Atomic Energy Agency (IAEA) [1], optimization processes which involves balancing radiation dose and image quality in radiology does not always lead to reduction in radiation dose. It is therefore important to emphasize that image quality must always be sufficient to meet clinical requirements. It is also essential to maintain the appropriate level of image quality required for clinical confidence. Image quality assessment plays an essential role in the various image processing applications. It seeks to quantify a visual quality or, anatomically, an amount of distortion (artifact) or degradation in a given picture. These distortions are inevitably part of any digital image processing chain from acquisition, processing and transmission of images [2]. A great deal of effort has been made to research which seeks to develop various image quality metrics that correlate very well with the perceived quality measurement but only limited success has been achieved [3].

Today, image quality is one of the most important aspects of diagnostic radiology. The concept of image quality has been undergoing a transformation with the widespread use of digital-projection radiography. The work of Mohammadi, Ebrahimi-moghadam, & Shirani, [4] suggests that the importance of efficient and reliable image quality evaluation has increased due to the increasing demand for image-based applications. This is due to the fact that assessing image quality is of fundamental importance for numerous image processing applications where the goal of image quality assessment methods is to automatically evaluate the quality of images in agreement with human quality judgements.

An ideal image is an image with high contrast, high spatial resolution and low noise level [5]. However, these factors are interconnected and depend on each other for every image. Image quality in medical imaging systems can be described and quantified by three characteristics namely; contrast, noise and sharpness. Contrast is mostly associated with screen film techniques whilst the derived quantity signal-to-noise ratio (SNR) is mostly associated with digital imaging technique as an important image quality parameter.

Generally image quality can be evaluated mostly by using two approaches; objective and subjective methods [2]. Subjective image quality assessment is by visual inspection of the 2-D images by human observer. Objective image quality assessment uses mathematical models to predict the quality of an image accurately and automatically.

Pascoal et al., [6] states that the routine assessment and control of image quality, both technical and clinical, is a fundamental task associated with good practice. In addition to subjective visual methods, currently, there are also available automated methods that can be used to assess technical image quality associated with diagnostic imaging systems.

Since the introduction of computed radiography (CR) in Ghana, no comprehensive evaluation of image quality and the determination of the potential for dose reduction consistent with acceptable image quality has been done to trigger the need for optimization of protection of patients. This study seeks to address the knowledge gap in the evaluation of image quality of clinical radiographs and provide the basis for optimization of the protection of the patient.

II. METHODS AND MATERIAL

Details of computed radiography systems used is presented in Table 1.

Table 1: Details of computed radiography systems used

Manufacturer	Year	Tube model number	Tube filtration	Max. kVp	Max. mAs
Philips Medical Systems	2002	989000085271	2.5 mmAl at 75 kVp	150	300
Schimadzu Corp.	2012	53224558	1.5 mmAl at 70 kVp	150	300

The study also employed beam alignment and Collimator test tools for the quality control process. Image quality was assessed using ImageJ software version 1.48 developed by the National Institute of Health, USA, that performs image quality assessment objectively [7].

Image Quality Assessment

Ten images were acquired for each type of examination considered from each CR system employed. Image quality was assessed using ImageJ software (version 1.48) to measure CNR and SNR. To calculate CNR, two regions of interest (ROIs) were marked on the images using the bespoke software (ImageJ). ROI1 was applied at an area of maximum density for example mid-way of the vertebral body and ROI2 in a region with a homogenous density (minimum density) as shown in Figure 1.

The CNR is then calculated using the standard equation 1 [8].

$$CNR = \frac{Mean\ signal\ of\ bone\ (ROI1) - Mean\ signal\ of\ tissue\ (ROI2)}{Standard\ deviation\ of\ ROI2} \quad (1)$$

The SNR was determined by inserting ROIs on the image as shown in Figure 2 and the calculation was done by using equation 2 [8]

$$SNR = \frac{Mean\ signal\ value\ within\ ROI}{Standard\ deviation\ within\ ROI} \quad (1)$$

Figure 2.1: Choosing regions of interest with ImageJ software for CNR

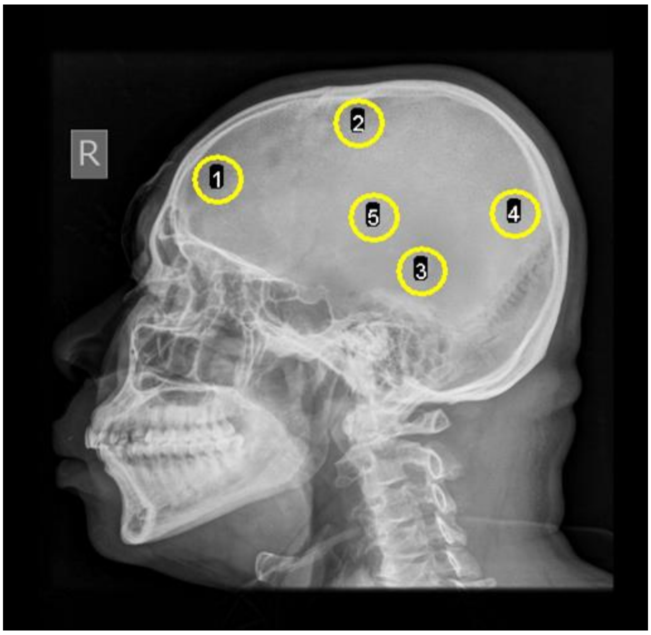

Figure 2.2: ROIs used for SNR calculation.

III. RESULTS AND DISCUSSION

A. Contrast-to-Noise Ratio

CNR is a measure for assessing the ability of an imaging procedure to generate clinically useful image contrast. The mean and standard deviation values of the calculated CNRs have been presented in Table 2.

The results in Table 2 and Figure 2 show that the highest CNR of 20.63 ± 8.65 was obtained for skull LAT projection at H-1 where the image was acquired at a kVp range of 62 to 64 kVp as against a lower value of 3.54 ± 3.27 where the examination was done at a kVp range of 70 to 74 kVp for the same anatomical projection at H-2.

Generally, Table 2 and Figure 2 show that the CNR obtained at H-1 for all the examinations were higher than the CNR recorded at H-2 except for skull AP and lumbar spine LAT projection where higher CNR was recorded at H-2 as against H-1. The variation in CNR between the two hospitals is mainly due to the difference in kVp used for the various examination. A similar result was obtained by Hess and Neitzel [9] who determined the CNR for paediatric extremities using kVp range of 40 kVp to 60 kVp. According to the authors, the highest CNR was obtained at 40 kVp. Also, the use of higher kVp technique is a well-known strategy to reduce dose on paediatrics, but at the same time decreases the CNR [10].

Table 2: Mean CNR calculated from images obtained for H-1 and H-2.

	Mean CNR		**Range of kVp**	
Area of Examination	**H-1**	**H-2**	**H-1**	**H-2**
Chest PA	12.8 ± 5.77	6.15± .14	62.0 - 68.0	120.0 - 125.0
Cervical spine AP	13.64 + 4.11	10.89 + 3.47	60.0 - 62.0	66.0 - 70.0
Cervical spine LAT	19.18 + 6.78	12.89 + 4.56	60.0 - 62.0	66.0 - 70.0
Lumbar spine AP	11.48 + 8.01	8.97 + 3.6	64.0 - 74.0	77.0 - 85.0
Lumbar spine LAT	3.79 + 11.97	4.81 + 3.51	80.0 - 95.0	96.0 - 98.0
Skull AP	7.43 + 3.02	9.89 + 3.87	73.0 - 75.0	75.0 - 78.0
Skull LAT	20.63 + 8.65	3.54 + 3.27	62.0 - 64.0	70.0 - 74.0

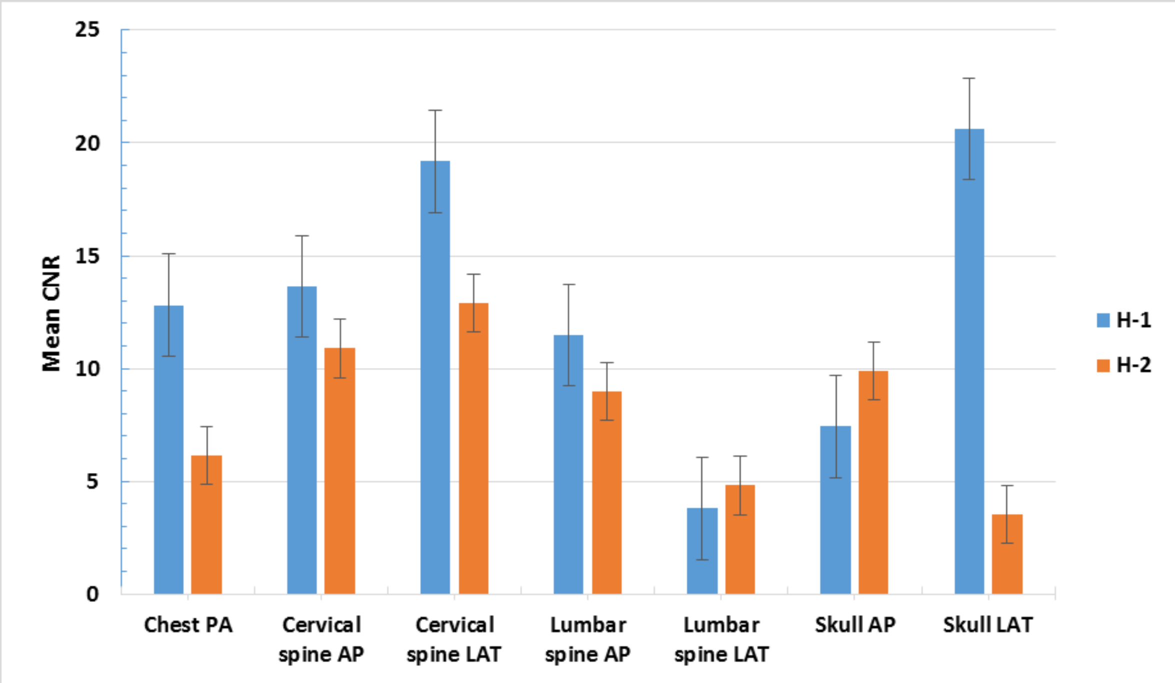

Figure 3: Comparative bar chart of mean CNR obtained from H-1 and H-2

The results of this study supports the assertion that the use higher kVp technique generally decreases the CNR. This is because with lower kVp, there is less scatter radiation reaching the detector with increasing mAs. Contrast is the most significant factor influencing the choice of tube potential for imaging different parts of the human body with different attenuations. The CNR obtained for objects containing several hundred pixels like radiograph has the potential to provide a useful parameter for comparing imaging performance for X-ray beams with different beam qualities. The relationship between the CNR measurements and tube potential in general reflects the variation in the number of details that can be detected [11].

B. Signal-to-Noise Ratio

One of the most common indicator of image quality is the SNR. The ability to detect an object (and hence resolve it from its neighbour) is related to the signal to noise ratio (SNR) of the object. SNR has been calculated for ten images which were used to determine the CNR. Table 3 and Figure 3 present the results obtained.

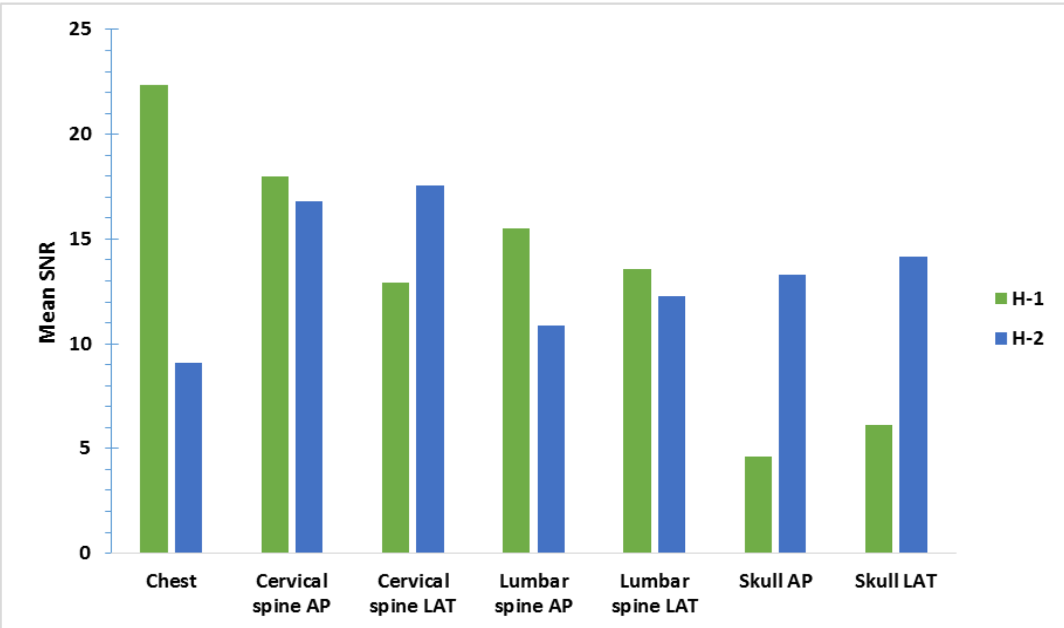

Figure 3: Comparative bar chart of SNR obtained from the two hospitals

The common way to quantify the level of noise in an image is to estimate the SNR. To be able to detect objects in a medical image, the threshold SNR is ≥ 5 [12]. This threshold was developed by Rose Albert who was interested to find the threshold value of SNR of an object to be visible by human observer and this is known as the Rose Model [12]. The assumption of the Rose Model is that the factor that limits the detection of an object in a radiographic image is the radiation dose used to produce the image [13]. Comparing the results obtained in Table 3 and the graphical representation in Figure 3 to the Rose Model show that 92.86 % of the images assessed had SNR greater than 5 for both hospitals except the SNR recorded for skull AP projection at H-1 which had a value lower than 5. This shows that clinicians would be able to extract useful information such as detection of bone fracture, pathology of a particular part of the human body, detection of injuries etc. from these images and there is the potential of reducing the dose patient received undergoing the examinations considered.

Table 3: Calculated SNR for the H-1 and H-2

	Mean SNR	
Area of Examination	**H-1**	**H-2**
Chest PA	22.35 ± 0.86	9.10 ± 0.81
Cervical spine AP	17.99 ± 7.67	16.81 ± 7.1
Cervical spine LAT	12.92 ± 3.93	17.58 ± 10.71
Lumbar spine AP	15.48 ± 1.27	10.85 ± 8.32
Lumbar spine LAT	13.59 ± 8.00	12.28 ± 3.46
Skull AP	4.63 ± 0.48	13.32 ± 9.37
Skull LAT	6.10 ± 3.60	14.17 ± 9.99

The differences in the SNR is due to the kVp and mAs factors used for the examination. This is because the selection of exposure parameters such as the increase of kVp and mAs result in more signal reaching the detector that should reduce the noise in the image and improve the SNR.

C. Optimization of Patient Protection

In order to ensure balance between dose and image quality for the various examinations, the study determined the patient dose at which the level of image quality would be acceptable for clinical practice in terms of CNR for all examinations. The level of CNR as a measure of image quality as well as low dose to patient has been summarized in the Table 4. The Table shows that lower entrance surface dose (ESD) can be achieved for various anatomical projections with acceptable level of CNR where useful information can be extracted from the radiographs.

Table 4: Optimized level of ESD and CNR

Type of Examination	CNR	ESD (mGy)
Chest PA	11.60	0.26
Lumbar spine AP	6.40	0.84
Lumbar spine LAT	3.60	3.26
Cervical spine AP	17.60	0.30
Cervical spine LAT	19.00	0.24
Skull AP	15.60	0.92
Skull LAT	4.60	0.38
Abdomen AP	10.65	0.26

The study is consistent with the work of Zainon et al [14] who investigated the radiation dose and image quality of X-ray radiographic imaging. Optimisation technique employed in radiology departments usually consists of selections of tube potential, filtration and method of scatter removal and there is a need to find an image quality parameter which can be used in clinical imaging tasks to compare and evaluate different options. CNR has been examined as such a parameter in this study. For a radiograph to be acceptable for diagnosis, it is dependent on its ability to display the correct anatomical part being imaged with optimum levels of CNR. In general, the relationship between the CNR measurements and tube potential reflects the variation in the detectability of objects in the image.

IV. CONCLUSION

The CNR calculated was in the range of 3.53 ± 3.27 to 20.63 ± 8.65. The results showed that the CNR obtained for H-1 were mostly higher than the CNR obtained at H-2. The differences were mainly due to the use of different kVp for the examinations. It was also found that lower kVp increases CNR which in turn decreases patient dose. The lowest CNR was recorded for skull LAT projection at H-2 whilst the highest CNR was also recorded for the same projection at H-1.

The SNR was calculated as a means of quantifying the level of noise in the images acquired from the CR systems used. There was a higher SNR of 22.35 $\pm$ 0.86 for chest PA examination at H-1 and a lower SNR of 4.63 $\pm$ 0.48 which also occurred at H-1 for skull AP projection. The results obtained was compared to the Rose model where the limit of SNR was set at ≥ 5. All the results obtained were greater than 5 except skull AP examination at H-1. The results therefore showed that the CR systems produce images that contain useful clinical information. The values of the CNR and SNR can be used as the baseline for future quality control monitoring and research. The relationships between CNR and the ESDs for all the examinations showed that there is a potential to reduce doses to patients while keeping images of diagnostic quality.

Thus, the findings of this work should be used to develop institutional level optimization of protection of patients consistent with clinically acceptable image quality.

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