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Original Paper

Association between subjective evaluation and physical parameters for radiographic images optimization

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A B S T R A C T

Purpose: The purpose of this study was to develop a methodology to optimize computed radiographic techniques to image the skull, chest, and pelvis of a standard patient.
Methods: Optimization was performed by varying exposure levels with different tube voltages to generate images of an anthropomorphic phantom. Image quality was evaluated using visual grading analysis and measuring objective parameters such as the effective detective quantum efficiency and the contrast-to-noise ratio. Objective and subjective evaluations were compared to obtain an optimized technique for each anatomic region.
Results: Gold standard techniques provided a significant reduction in X-ray doses compared to the techniques used in our radiology service, without compromising diagnostic accuracy. They were chosen as follows 102 kVp/1.6 mAs for skull; 81 kVp/4.5 mAs for pelvis and 90 kVp/3.2 mAs for chest.
Conclusion: There is a range of acceptable techniques that produce adequate images for diagnosis in computed radiography systems. This aspect allows the optimization process to be focused on the patient dose without compromising diagnostic capabilities. This process should be performed through association of quantitative and qualitative parameters, such as effective detective quantum efficiency, contrast-to-noise ratio, and visual grading analysis.

Introduction

Optimization of radiographic techniques aims to balance image quality and exposure dose to the patient and is outlined in the As Low As Reasonably Achievable (ALARA) principle [1–3]. Dose levels are related to image quality, but it should not be minimized to a degree that compromises diagnostic capabilities [1,2,4–6].

Image quality can be estimated subjectively using a Visual Grading Analysis (VGA), which is a direct analysis of the image by radiologists and can be performed in anthropomorphic phantom radiographs [7]. However, particularly with digital systems, sometimes VGA is not sufficient to make distinctions between different techniques.

In this case, objective parameters are extremely useful to investigate image quality and numerous attempts were made to optimize digital radiography systems. For example, some authors investigated the association of signal-to-noise ratio (SNR) and clinical observer evaluations to optimize images [8]. Additionally contrast-to-noise ratio (CNR) was used to optimize beam quality for regions of different attenuation such as the lung, heart, and abdomen [9].

Other metrics such as the detective quantum efficiency (DQE) and the effective DQE (eDQE) have been used to assess image quality in digital radiography systems [10,11]. The eDQE seems adequate to characterize system performance in a relevant clinical context, although it lacks the incorporation of the risk to the patient, which is evidenced by the effective dose measurement. The effective dose efficiency (eDE) managed to incorporate the effective dose into the eDQE metric and has been evaluated in chest radiographs [12].

However, in our understanding the incorporation of the effective dose value into the eDQE metric could influence the choice of an optimal technique over another with better performance in radiography systems. Therefore, in this present study we chose to analyze the eDQE and the effective dose separately and balance those two parameters to choose radiographic techniques with lower risk for the patient.

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The aim of this paper was to investigate the image quality of the skull, chest, and pelvic examinations in computed radiography systems. We performed the VGA of an anthropomorphic phantom and analyzed physical parameters such as effective detective quantum efficiency, effective dose and contrast-to-noise ratio.

Methodology

The radiographic system and the phantoms description

An Agfa CR 85-X digitizer (Agfa-Gevaert Group, Mortsel, BE) was used with MD 4.0 general cassette plates ($35\ cm \times 35\ cm^2$, effective pixel pitch of 0.1 mm). The CR system and the cassette plates were tested in accordance with the quality control tests [13]. The general purpose X-ray room consisted of three-phase equipment (Multix B, Siemens AG Medical Engineering, Germany) with a total inherent filtration of 2.5 mm of aluminum and employing a stationary grid with a 5:1 grid ratio. Aiming for maximum reproducibility, one image plate (IP) was used for each examination and all procedures were repeated three times. In addition, a delay of 10 minutes occurred between exposures and readings.

The study was performed with two different phantoms: the homogeneous phantom and the anthropomorphic (Alderson Rando – AR). The homogeneous phantom was the patient equivalent phantom (PEP) for skull, pelvis and chest (*American National Standard Institute PH2/43*, 1982). The skull and pelvis were simulated by the same phantom configuration (PEP Skull/Pelvis) since, according to Gray [14], scattering in these anatomic regions is similar. The skull/pelvis PEP consisted of four pieces of clear acrylic polymethylmethacrylate (PMMA) measuring $30.5 \times 30.5 \times 2.54\ cm^3$, a piece of aluminum (type 1100 alloy) measuring $30.5 \times 30.5 \times 0.3\ cm^3$, and an additional piece of PMMA measuring $30.5 \times 30.5 \times 5.08\ cm^3$. The chest PEP consisted of four pieces of PMMA measuring $30.5 \times 30.5 \times 2.54\ cm^3$, a piece of aluminum measuring $30.5 \times 30.5 \times 0.3\ cm^3$, and a 5.08 cm air gap. The anthropomorphic phantom was the Alderson-Rando (AR) phantom [15,16], which consisted of a natural human skeleton embedded in a synthetic isocyanate rubber with a lung substitute and air cavities. This simulates an average male patient (~73 kg). We also inserted tubular structures (4 mm in diameter and 15 cm in length) containing water into the chest region to simulate a vascular pattern.

Table 1
Skull test techniques obtained with the skull PEP with the kVp, mAs and VGA values.

kVp	mAs values/VGA scores				
70	7.1	8	9	10.0	11
	−0.67	1.33	1.67	0.67	−0.67
75	5	5.6	6.3	7.1	8
	1.00	1.67	2.00	0.33	0.67
81	3.6	4	4.5	5.0	5.6
	0.67	1.00	1.67	1.33	0.33
85	2.8	3.2	3.6	4.0	4.5
	1.00	0.00	2.00	0.67	−0.33
90	2.2	2.5	2.8	3.2	3.6
	0.33	2.00	0.67	0.67	−0.33
96	1.8	2	2.2	2.5	2.8
	1.33	1.00	2.00	−0.67	−0.67
102	1.4	1.6	1.8	2.0	2.2
	0.00	2.00	1.00	1.33	0.67
105	1.25	1.4	1.6	1.8	2
	0.67	2.00	1.33	0.33	0.00
109	1.25	1.4	1.6	1.8	
	2.00	0.67	0.67	0.67	
117	1.25	1.4			
	2.00	0.67			

Table 2
Pelvis test techniques obtained with the pelvic PEP with the kVp, mAs and VGA values.

kVp	mAs values/VGA scores				
70	7.1	8	9	10.0	
	0.67	1.00	1.67	0.33	
75	5	5.6	6.3	7.1	8
	0.67	−0.67	1.67	0.67	0.33
81	3.6	4	4.5	5.0	5.6
	−1.33	0.67	2.00	1.00	−1.33
85	2.8	3.2	3.6	4.0	4.5
	0.67	0.33	2.00	0.00	0.33
90	2.2	2.5	2.8	4.0	
	1.00	1.00	1.67	0.67	
96	2	2.5	2.8		
	−0.33	2.00	1.00		
102	1.4	1.6	1.8	2.0	2.5
	0.00	0.67	−0.67	2.00	0.00
105	1.25	1.4	1.8	2.0	
	1.00	−0.33	1.33	0.00	
109	1.25	1.4	1.6	1.8	
	0.33	0.00	2.00	0.33	
117	1.25	1.4			
	−0.67	1.67			

Imaging and VGA image quality evaluations

An initial series of exposures were performed with the PEP phantom. Nominal peak tube potentials varied between 70 and 117 kVp in approximately 5 kVp steps. Each kVp correlated with 5 mAs values. This procedure resulted in radiological techniques (hence forth called test-techniques) for the skull, chest, and pelvic examinations which are described in Tables 1–3. The lgM values (Agfa exposure index) were monitored in each test-technique by collimating the images to the entire area of the PEP. The AR phantom [15,17] was then imaged at the appropriate anatomical regions using the test-techniques. All chest techniques were generated with exposure times less than 20 ms to avoid cardiac motion artifacts [2].

For all measurements, the PEP was centered in the radiation field. The source-detector distance (SDD) was 1.0 m to image the skull and pelvis, and 1.8 m for chest. The tube collimator was adjusted to yield a radiation field of $35.0 \times 35.0\ cm^2$. Entrance Surface Doses (ESDs) were monitored on the surface of the PEP with a dosimetric system that consisted of a 9015 electrometer (Radcal Corp., Monrovia, CA, USA) and a properly calibrated ionization chamber (model 10X5–6 cc, Radcal Corp.). The effective dose (ED) values were estimated from ESDs measured, simulations and organ weighting factors obtained from ICRP 103 [18] using an online Monte Carlo

Table 3
Chest test techniques obtained with the chest PEP with the kVp, mAs and VGA values.

kVp	mAs values/VGA scores						
75	5.6	6.3	7.1	8.0	9	10	–
	−0.67	0.33	1.67	1.00	1.00	−1.00	
81	4.5	5	5.6	6.3	7.1	–	–
	1.00	2.00	−0.33	0.67	−0.33		
85	3.6	4	4.5	5.0	5.6	–	–
	0.67	2.00	0.67	0.33	−0.33		
90	2.5	2.8	3.2	3.6	4	–	–
	0.67	0.67	1.67	1.00	0.33		
96	1.6	2.2	2.5	2.8	3.2	3.6	
	−1.67	−0.33	0.33	1.33	2.00	0.33	
102	1.25	1.4	1.6	1.8	2	2.2	2.5
	−1.00	−1.33	0.00	1.00	1.33	1.67	0.00
105	1.4	1.6	1.8	2.2	2.8	–	–
	−1.67	−0.67	0.67	1.00	1.67		
109	1.25	1.4	1.6	1.8	2	–	–
	−2.00	−0.33	0.67	1.00	2.00		
117	1.25	1.4	1.6	1.8			
	0.33	1.33	2.00	1.33			