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Original research article

Image Quality Comparison and Clinical Evaluation for U-Arm Digital Radiography

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ABSTRACT

The aim of this research was to assess the image quality and clinical evaluation for the proposed U-arm digital radiography system. The development of the proposed U-arm digital radiography system includes both hardware and software parts. The quality of images from the proposed system was tested and compared with three different machines using a radiographic image quality phantom and a radiographic chest phantom. Then two specialized radiologists conducted clinical evaluation based on visual grading analysis. The experimental results show that the X-ray image from the proposed machine yielded the high-contrast resolution of 3.1 line pairs per mm, while others were in the range of 2.8-3.4 line pairs per mm. The low contrast detectability and grayscale level discrimination are comparable to other machines. Two specialized radiologists evaluated the image quality of 42 volunteers and the overall satisfaction was about 82%. The image quality of the proposed digital radiography machine using the phantom is comparable to other digital radiography machines. Moreover, the evaluation from two radiologists confirms its capability for screening and diagnosis in chest imaging.

Keywords: Digital radiography; X-Ray; Medical imaging; Chest imaging; Clinical evaluation

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1. Introduction

Digital radiography (DR) offers many advantages over film-based radiography, such as immediate image display, no film processing and room storage, wider dynamic range and lower radiation dose. Since the machine can immediately display a 2D digital X-ray image, a physician can perform a quick diagnosis and an accurate treatment plan. The proposed machine called BodiiRay is a U-arm-type digital radiography machine that has been researched and developed by the National Electronics and Computer Technology Center (NECTEC) and the National Metal and Materials Technology Center (MTEC) under the National Science and Technology Development Agency (NSTDA) as shown in Fig. 1. The proposed machine is aimed to visualize anatomical structures around the lung area in 2D images for screening and diagnosis [1-4]. The mechanical structures and electrical systems of the machine were designed to reduce costs but remain good quality and high performance as compared to other commercial digital radiography machines. The software system includes three parts: 1) the main software for database management of patients 2) acquisition and preprocessing; and 3) the viewer software for image processing and viewing images called BodiiView.

Fig. 1. The proposed 2D digital X-ray machine.

Before clinical usage, the evaluation of image quality for the machine is usually required to ensure its performance since the diagnosis mainly depends on the quality of the image. A number of articles have been published regarding the subjects [1-11]. In those studies, some evaluating methods were proposed, such as manual scoring of the phantom image [1, 6, 7, 11], statistical methods [1, 5, 9, 11], and image quality evaluation on human subjects by radiologists [2, 3, 4, 8, 10, 12].

In this paper, the authors evaluated the image quality of the proposed digital radiography machine by using a radiographic survey phantom and a radiographic chest phantom and then compared with other machines available in the market. After the ethics committee approved the clinical trial on volunteer patients, clinical evaluation was conducted.

2. Materials and Methods

2.1 The proposed machine

The studied U-arm digital radiography uses a high frequency X-ray generator and a flat panel detector constructing through a U-shaped gantry. The flat panel detector used in this system is based on the amorphous silicon (a-Si) thin film transistor (TFT) flat panel with the size of 17 in x 17 in and the image size of 3000 x 3000 pixels [13]. The overall specifications of the system are summarized in Table 1.

Table 1. Specifications of the proposed digital radiography.

Specifications	**Description**
Tube Voltage	40 - 125 kVp
Tube Current	10 - 500 mA
Exposure Time	1 ms – 10 s
mAs	0.1 – 500 mAs
Generator Power	40 kW
Focal Spot	0.6 / 1.2 mm
Detector Type	Gadolinium Oxysulfide Scintillator (Gd2O2S)
Detector Size	17”x17”
Detector Pitch	0.143 mm
Image Size	3000 x 3000 pixels
Source to Detector Distance	100-180 cm
Power Requirement	100-240 VAC, 50-60 Hz, Single Phase, 8A

2.2 The proposed software

The software for the proposed U-arm digital radiography consists of three parts: 1) the main software 2) acquisition and preprocessing and 3) viewer software. The main software integrates all the software parts and the hardware parts as well as database management systems. Moreover, it is connected to PACS (Picture Archiving and Communication System) for receiving the patient worklist and exporting DICOM (Digital Imaging and Communications in Medicine) [14-15] image. Raw images directly acquired from the digital flat panel detector usually provide low quality of the image. The poor quality of acquired raw images aforementioned is not suitable for diagnosis, thus to improve the image quality, the authors developed the pre-processing method in the software which is the combination of the normalization function and the CLAHE algorithm [7,16] (Fig. 2). This increased the contrast of the images as well as improved the visibility of anatomical structures of the patient such that the lungs, heart, airways, blood vessels, and spine can be visualized easily. Once the pre-processing stage was finished, the image was then converted to a DICOM standard, which is a standard for handling, storing, printing, and transmitting information in medical imaging.

To display the 2D processed X-ray image, the authors developed our in-house DICOM viewer software, called BodiiView, based on Java programming and ImageJ library [17] as shown in Fig. 3. A user can view the X-ray image in the DICOM format easily and rapidly. The DICOM viewer provides not only basic features, such as multiple layout displays, measurement tools, annotation, zoom, rotation and window/level adjust, but also advanced image processing, such as lung segmentation and the cardiothoracic ratio (CTR) [18] for heart size diagnosis. In addition, semi-automatically image enhancement to reduce noise or sharpen images can be performed. Moreover, BodiiView supports not only exporting the X-ray image data to CD, but also connecting and uploading the X-ray image data to PACS.

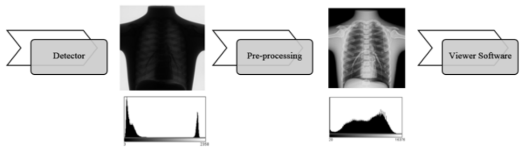

Fig. 2. Pre-processing method.

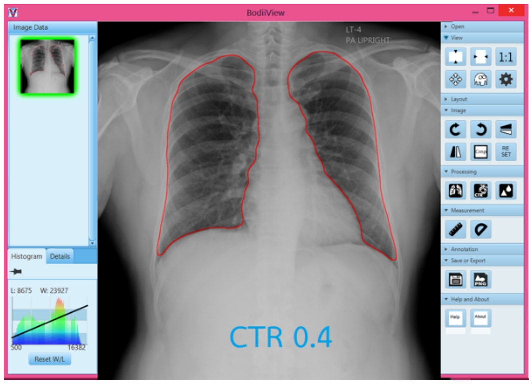

Fig. 3. Viewer software with the lung segmentation feature.

2.3 Image quality with phantoms

Image quality assessment was first evaluated by using a radiographic survey phantom (Gammex 170NJ, Gammex Inc., USA) [19] in terms of high contrast resolution, low contrast detectability, and grayscale level discrimination as shown in Fig. 4. The high contrast resolution test tool contains a 20 line pair chart from 0.6 line pairs per mm to 10.0 line pairs per mm, i.e., the higher line pair value the better image quality. The low contrast resolution part consists of two rows having different diameters and heights of small holes. The first row contains eight holes of 0.375 inch in diameter with decreasing depths of 0.006, 0.009, 0.013, 0.018, 0.025, 0.035, 0.049 and 0.068 inch. The second row has four holes of 0.068 inch in depth with decreasing diameters of 0.20, 0.15, 0.10, 0.08 inch on both left and right sides. The smaller depth value or the smaller diameter value yields the better image quality. In addition, an aluminum step wedge contains 11 steps of different aluminum thickness such that different shades of grayscale levels in the X-ray image can be discriminated as shown Fig. 4.

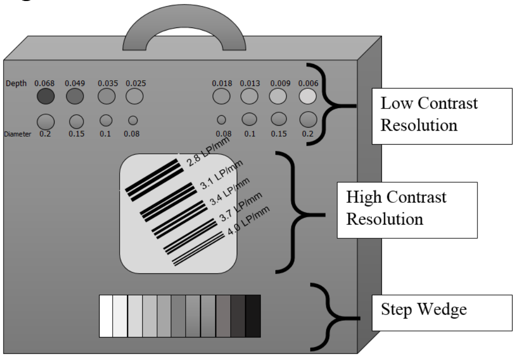

Fig. 4. A radiographic survey phantom.

Moreover, the visual assessment was evaluated by a radiographic chest phantom (Radiology Support Devices: RS-315, RSD Phantoms, USA) [20] as shown in Fig. 5. It imitates the structure of heart, lungs, airways, blood vessels and spine.

Fig. 5. Anthropomorphic chest phantom.

2.4 Clinical evaluation

Clinical evaluation was performed in terms of satisfaction by two specialized radiologists. Data analysis used statistics including mean and standard deviation. This prospective study was conducted in 42 adult volunteers [4] separating into three groups according to a body mass index (BMI) (20); S: Small (BMI < 18.5), M: Medium (18.5 ≤ BMI ≤ 23), L: Large (BMI > 23). Two specialized radiologists evaluated the quality of clinical images using visual grading analysis in five grading scores [3]. The scale from 1 to 5 grading was defined as 1 = "not visible", and 5 = "clearly visible". The questionnaire [3] targeting radiologists consist of 10 questions regarding of anatomical structures and their image quality as shown in Table 6.

3. Experimental Results

The proposed digital radiography system was compared with three commercial DR machines including Philips: DigitalDiagnost, which is a ceiling-type DR machine [21]; Philips: Essenta DR compact, which is a U-arm digital X-ray [22]; and Samsung: XGEO GU60, which is a U-arm digital X-ray [23]; using the setting as shown in Table 2.

Table 2. Chest X-ray setting and detector specification of different machines.

X-ray Setting	**BodiiRay NSTDA**	**Philips Digital Diagnost**
Tube Voltage	80 kV	102 kV
Tube Current	200 mA	875 mA
Exposure Time	25 ms	8 ms
mAs	5 mAs	7 mAs
Detector Type	Gd2O2S	CsI
Pixel Spacing	0.143 mm	0.145 mm
Distance	180 cm	180 cm

X-ray Setting	**Philips Essenta DR Compact**	**Samsung XGEO GU60**
Tube Voltage	85 kV	90 kV
Tube Current	764 mA	220 mA
Exposure Time	5.23 ms	36.36 ms
mAs	4 mAs	8 mAs
Detector Type	CsI	CsI
Pixel Spacing	0.173 mm	0.143 mm
Distance	180 cm	180 cm

Table 3. Comparison of image quality of different machines.

Image Quality	BodiiRay NSTDA	Philips Digital Diagnost
High Contrast Resolution	3.1 lp/mm	3.4 lp/mm
Low Contrast Resolution 1st row (max)	Depth 0.025 in diameter 0.375 inch	Depth 0.025 in diameter 0.375 inch
Low Contrast Resolution 2nd row (max)	Depth 0.068 in diameter 0.080 inch	Depth 0.068 in diameter 0.080 inch
Aluminum Step Wedge	11 steps	11 steps

Image Quality	Philips Essenta DR Compact	Samsung XGEO GU60
High Contrast Resolution	2.8 lp/mm	3.1 lp/mm
Low Contrast Resolution 1st row (max)	Depth 0.013 in diameter 0.375 inch	Depth 0.025 in diameter 0.375 inch
Low Contrast Resolution 2nd row (max)	Depth 0.068 in diameter0.080 inch	Depth 0.068 in diameter 0.080 inch
Aluminum Step Wedge	11 steps	11 steps

Table 3. summarizes the image quality of different machines, such as high-contrast resolution, low contrast detectability and grayscale readings from different machines, respectively. A blind technique was used to evaluate the images in this stage.

From Table 3, image quality assessment was evaluated by a radiographic survey phantom (Gammex 170NJ). The high contrast resolution part contains different line pairs between 0.60 lp/mm to 10.00 lp/mm. The higher line pair value means the better high contrast resolution.

BodiiRay provided the high contrast resolution of 3.1 lp/mm; Philips Digital Diagnost provided the high contrast resolution of 3.4 lp/mm.

Phillips Essenta DR Compact provided the high contrast resolution of 2.8 lp/mm and Samsung provided the high contrast resolution of 3.1 lp/mm.

When authors compared BodiiRay results with other three different commercial X-ray machine. Althought the high contrast resolution of BodiiRay may make some noise on image, the result shows that BodiiRay gives the closed line pair number of image quality with Samsung machine.

From Table 3, the low contrast detectability part contains eight holes of 0.375 in diameter with the depths of 0.006 to 0.068 in. The smaller depth value means the better low contrast resolution. BodiiRay provided the low contrast resolution of Depth 0.025 in. Philips Digital Diagnost provided the low contrast resolution of Depth 0.025 in. Phillips Essenta DR Compact provided the low contrast resolution of Depth 0.013 in and Samsung provided the low contrast resolution of Depth 0.025 in.

When authors compared BodiiRay results with other three different commercial X-ray machine. Although the low contrast resolution of BodiiRay may make some noise on image; the result shows that BodiiRay gives the nearest number of image quality with Philips Digital Diagnost and Samsung machine at Depth value 0.025 in.

From Table 3, a radiographic survey phantom contains 11 different of aluminum step wedge to distinguish different shades of gray values for measurement and analysis of X-ray beam quality. When authors compared BodiiRay result with other three different commercial X-ray machine.

In terms of quality, it shows that BodiiRay result and other three different commercial X-ray machines perform equally well, as regards quality that visibility of all aluminum steps. Moreover, the images of the anthropomorphic chest phantom using the recommend X-ray setting from radiological technologists as described previously are shown in Fig. 6 to verify the visualization of human-equivalent anatomical structures.

From Fig. 6, Visual assessment was evaluated by a radiographic chest phantom (Radiology Support Devices: RS-315). This phantom imitates the structure of heart, lungs, airways, blood vessels and spine. The visual results of BodiiRay, Philips Digital Diagnost, Philips Essenta DR compact and Samsung using the chest phantom show that the image from BodiiRay looked hardly different.

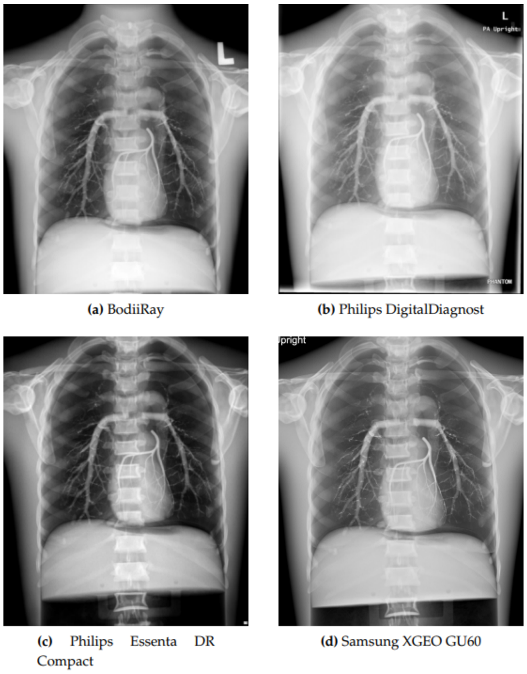

Fig. 6. Images of the chest phantom.

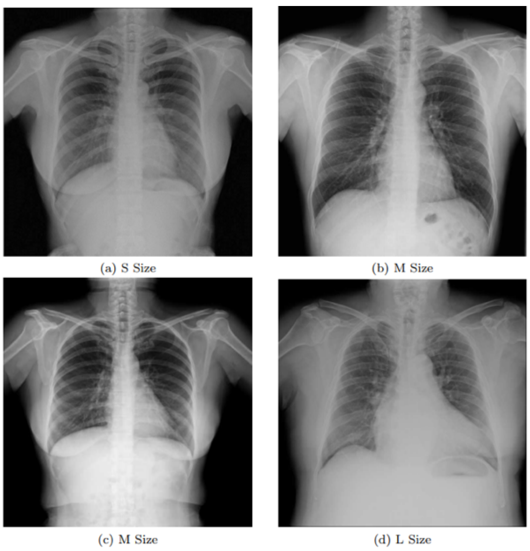

Fig. 7. Example of chest X-ray images on volunteers.

3.1 Radiologists' satisfaction

After image quality assessment with a survey phantom finished, the BodiiRay system was tested on forty-two volunteers for clinical evaluation. These volunteer patients including 23 males and 19 females with age between 17-78 years old were divided into 3 groups according to the BMI as in Table 4 and statistically analyzed in detail as shown in Table 6. The questionnaires in Table 5. were adopted from the Department of Diagnostic Radiology, University of Heidelberg [3]. Clinical evaluation from two specialized radiologists are summarized in Table 5. The examples of human chest images from volunteers with different sizes are shown in Fig. 7. These images were acquired with different X-ray setting protocols according to BMI. For example, the sample volunteers in the S, M, and L groups were acquired at 80 kV, 4 mAs; 80 kV, 5 mAs; and 90 kV, 10 mAs, respectively.

Table 4. Number of volunteers.

Body Size	Number of volunteers
S Group (BMI <18.5)	10
M Group (18.5 <= BMI <= 23)	20
L Group (BMI >23)	12
Summary	42

Table 5. Clinical evaluation.

No.	Attitude questions	Mean	S.D.
1.	Ability to see lungs	4.04	1.11
2.	Ability to see heart	4.13	1.11
3.	Ability to see bronchiole	4.06	1.12
4.	Ability to see spine	4.01	1.00
5.	Ability to see bone	4.20	0.94
6.	Ability to see bone texture	4.17	0.96
7.	Contrast/brightness	4.07	1.07
8.	Image quality	4.13	1.04
9.	Overall satisfaction	4.08	1.02
10.	Confidence in image results	4.18	0.78

Table 6. Volunteer's statistics.

Size	Gender	Attributes	Mean	Std. Deviation	Minimum	Maximum	Median
Small	Male N=5	age	19.60	2.19	18.00	22.00	18.00
		weight	50.20	2.68	46.00	53.00	50.00
		height	170.60	4.28	164.00	175.00	172.00
		bmi	17.28	0.59	16.70	18.20	17.10
	Female N=5	age	20.40	2.97	17.00	24.00	19.00
		weight	44.36	6.12	37.00	52.80	42.00
		height	160.10	7.20	150.00	169.50	162.00
		bmi	17.23	1.08	16.00	18.40	17.00
Medium	Male N=9	age	31.56	20.99	18.00	69.00	18.00
		weight	62.09	5.02	50.10	67.00	63.00
		height	170.89	4.59	163.00	176.00	172.00
		bmi	21.26	1.39	18.90	23.50	21.10
	Female N=11	age	28.00	12.22	18.00	50.00	22.00
		weight	52.45	7.80	42.00	64.00	52.00
		height	159.09	7.63	147.00	168.00	160.00
		bmi	20.61	1.56	18.90	22.80	20.40
Large	Male N=9	age	26.78	12.19	18.00	48.00	19.00
		weight	80.90	12.39	64.00	102.00	79.50
		height	171.83	5.73	163.00	180.00	172.00
		bmi	27.26	2.75	24.10	31.50	27.40
	Female N=3	age	61.00	16.52	45.00	78.00	60.00
		weight	63.33	9.83	55.60	74.40	60.00
		height	151.00	2.65	149.00	154.00	150.00
		bmi	27.88	5.14	23.44	33.51	26.70
Total	Male N=23	age	27.09	15.37	18.00	69.00	19.00
		weight	66.87	14.81	46.00	102.00	64.00
		height	171.20	4.82	163.00	180.00	172.00
		bmi	22.74	4.42	16.70	31.50	22.10
	Female N=19	age	31.21	17.38	17.00	78.00	23.00
		weight	52.04	9.52	37.00	74.40	52.00
		height	158.08	7.40	147.00	169.50	159.00
		bmi	20.87	4.06	16.00	33.51	19.38
	Total N=42	age	28.95	16.24	17.00	78.00	22.00
		weight	60.16	14.60	37.00	102.00	59.95
		height	165.26	8.95	147.00	180.00	167.25
		bmi	21.89	4.31	16.00	33.51	21.05

Note: The terms of this arrangement and the clinical trial on volunteer patients have been reviewed and approved by the ethics committee no.1 of the Faculty of Medicine, Thammasat University (Project No. MTU-EC-RA-5-106/57) in accordance with its conflict of interest policies.

4. Discussion

The phantom comparison of different machines yields similar image quality. BodiiRay provided the high-contrast resolution of 3.1 line pair/mm, while other machines were ranged between 2.8 - 3.4 line pair/mm. The high contrast resolution of Philips DigitalDiagnost seems to be a little higher than others. One of the reasons might be due to the X-ray setting. From Table 3, Philips DigitalDiagnost has the highest radiation dose, thus lower noise may results in better line pair reading. On the other hand, the lowest high contrast resolution is Philips Essenta DR Compact since the pixel spacing is slightly larger than others. Due to the low tube voltage setting of Philips Essenta DR Compact, it has a little better contrast detectability than others.

From Table 5, the satisfaction of expert radiologists toward the quality of the images shows that the evaluation scores are ranged from 4.01 to 4.20 out of 5 points and the visualization of the bone has the maximum score of 4.20. The average of all ten evaluating questions is 4.11 or about 82%, which is in the satisfied range [3].

5. Conclusions

This paper proposed the image quality comparison and clinical evaluation of the proposed U-arm digital radiography. The quality of images was evaluated using a radiographic survey phantom in terms of high contrast resolution, low contrast detectability and grayscale level discrimination. The results showed that its image quality were comparable to other digital radiography machines. Two specialized radiologists using visual grading analysis on forty-two volunteers performed the clinical evaluation of the proposed machine. The overall evaluation in human subjects has 82% satisfaction. These results confirm that the proposed machine is suitable for clinical use.

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Appendix

Conflict of interests: The authors declare no conflict of interest.

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Informed consent: Volunteer patients have been informed consent before conducting a healthcare intervention. Informed consent was obtained from all individual participants included in the study.

Ethical approval: The terms of this arrangement and the clinical trial on volunteer patients have been reviewed and approved by the ethics committee no.1 of the Faculty of Medicine, Thammasat University (Project No. MTU-EC-RA-5-106/57) in accordance with its conflict of interest policies.