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Comparison of different phantoms used in digital diagnostic imaging

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ABSTRACT

The organs of extremity, chest, skull and lumbar were physically simulated using uniform PMMA slabs with different thicknesses alone and using these slabs together with aluminum plates and air gaps (ANSI Phantoms). The variation of entrance surface air kerma and scatter fraction with X-ray beam qualities was investigated for these phantoms and the results were compared with those measured from anthropomorphic phantoms. A flat panel digital radiographic system was used for all the experiments. Considerable variations of entrance surface air kermas were found for the same organs of different designs, and highest doses were measured for the PMMA slabs.

A low contrast test tool and a contrast detail test object (CDRAD) were used together with each organ simulation of PMMA slabs and ANSI phantoms in order to test the clinical image qualities. Digital images of these phantom combinations and anthropomorphic phantoms were acquired in raw and clinically processed formats. Variation of image quality with kVp and post processing was evaluated using the numerical metrics of these test tools and measured contrast values from the anthropomorphic phantoms. Our results indicated that design of some phantoms may not be efficient enough to reveal the expected performance of the post processing algorithms.

1. Introduction

The optimization of the image quality and patient radiation exposure is one of the main requirements for clinical radiological imaging. Real patients can be used for the radiation measurements; however specific phantoms are needed for image quality assessments. Number of phantoms is designed to accomplish both tasks simultaneously for this optimization.

The sharpness and noise are the important parameters used to define the quality of the radiographic images. Their quantitative assessments are performed by physical measurements. For example, the sharpness and the noise of imaging systems can be described in the frequency domain by the modulation transfer function (MTF), and by the normalized noise power spectrum (NNPS) respectively. Detective quantum efficiency (DQE) is determined from these metrics and gives the efficiency of a detector when using input signal-to-noise ratio provided by a limited number of photons to form an image at a certain dose level [1–3]. However, these measures cannot provide detailed information for the clinical performance of the imaging system. Different types of test objects and phantoms are employed for this task and evaluation of the image quality can be achieved by visual assessment and/or numerical measurements such as contrast, contrast to noise ratio, signal to noise ratio, high contrast spatial resolution, and threshold contrast detail detectability [4]. These tools are generally used with uniform slabs (acrylic, aluminum or copper) aiming to represent the scatter and attenuation properties of the human body to employ the exposure conditions similar to clinical examination. Radiation dose measurement at the surface of these combinations can also be done together with image quality investigations. The construction of these test objects should be sensitive enough to reflect the exposure and beam quality variations encountered in clinical exams. As it is widely known, the human body is best represented by the anthropomorphic phantoms; dose measurements on these phantoms better reflect the real patient studies. Image quality evaluations for these phantoms can be done visually and also with contrast measurement among the different tissue structures.

In digital radiology user can change the image contrast and sharpness by applying post processing software tools and filters. There are numbers of processing filters in each system which are changing from one vendor to other one. Although no clear explanations about these tools are supplied by the majority of the vendors, users are allowed to modify some of the variables of these filters causing dramatic changes on the appearance of images. Phantoms play an important role in this respect to see the effects of image processing algorithms together with the variation of exposure conditions in clinical digital images.

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The purpose of this work is to investigate the efficiency of different phantoms when they are used for the performance test of clinical radiographic images obtained with flat panel detector. Entrance surface air kerma measurements were carried out on simple PMMA slabs at different thicknesses simulating some of the human organs, ANSI organ phantoms and anthropomorphic phantoms using different beam qualities. The raw and clinically processed images of a low contrast test tool and a contrast detail test object sandwiched between these slabs and ANSI phantoms as well as the images of the anthropomorphic phantoms were obtained. Image quality was numerically evaluated using the raw and clinically processed images together with the radiation doses measured on the phantom surfaces and scatter fractions.

2. Material and methods

An analog X-ray system (GE Silhouette VR) was used together with a wireless indirect flat panel detector (Carestream DRX-1 C) with a pixel size of 0.139 μm for all the measurements. Digital images were collected using the default clinical acquisition protocols of the system. These images were also acquired in service mode (pattern), so that there was no gray scale modification or post processing in the images. An antiscatter grid with a ratio 10:1 and frequency of 40 lp/cm was used for all the exposures. The half value layer (HVL) of the X-ray tube was measured as 3.5 mm-Al at the tube voltage of 80 kVp. The quality control of X-ray generator, X-ray tube and detector was carried out according to the protocols given in the literature [5,6].

Three different physical phantoms for the simulations of different organs and/or patient sizes were used (Fig. 1):

1. Homogeneous PMMA slabs with 10, 15, 20 and 25 cm thicknesses and 20 cm × 20 cm sizes,
2. ANSI phantoms [7]; extremity (30.5 cm × 30.5 cm × 2 mm aluminum between two 30.5 × 30.5 cm × 2.54 cm acrylic), skull (four 30.5 cm × 30.5 cm × 2.54 cm acrylic, 3 mm aluminum, and a 5.08 cm acrylic), chest (30.5 cm × 30.5 cm acrylic 2.54 cm acrylic, 3 mm aluminum and a 5.08 cm air gap) and lumbar (30.5 cm × 30.5 cm × 17.78 cm acrylic, and 7 cm × 30.5 cm aluminum, 4.5 mm thick to provide additional attenuation in the spinal region),
3. Anthropomorphic phantoms representing human thorax, knee, and the abdomen and skull parts of the Rando phantom (Alderson Research Laboratories)

The phantoms and the PMMA slabs were categorized in four groups; the exposures of anthropomorphic knee, ANSI extremity and PMMA slab with 10 cm thickness were taken at 60 kVp, 65 kVp and 70 kVp settings. The representative of the skull group including skull part of Rando, ANSI skull and 20 cm thick PMMA slab was exposed at 70 kVp, 80 kVp and 90 kVp. The chest group exposed at 90 kVp, 110 kVp and 125 kVp using the anthropomorphic thorax, ANSI chest and the PMMA slabs of 15 cm and 20 cm thicknesses. The abdomen part of the Rando, ANSI lumbar and 25 cm thick PMMA were the last group and exposed at the kVp settings of 70 kVp, 80 kVp and 90 kVp. The thicknesses of the PMMA slabs were selected as the equivalent thickness of ANSI phantoms using Xcomp5r simulation program [8]. Focus to detector distances was 127 cm for all the exposures and mAs values were tried to be adjusted to achieve target detector doses around 2.5 μGy at each exposure.

Entrance surface air kerma was measured for each phantom; Exposure readings were made in air at a distance of 25 cm above the phantom and subsequently corrected for the distance and multiplied by the back scatter factors [9]. An ion chamber (AccuPro 10 × 60OR, RadCal Monrovia, California) calibrated at the SSDL was used for all the measurements.

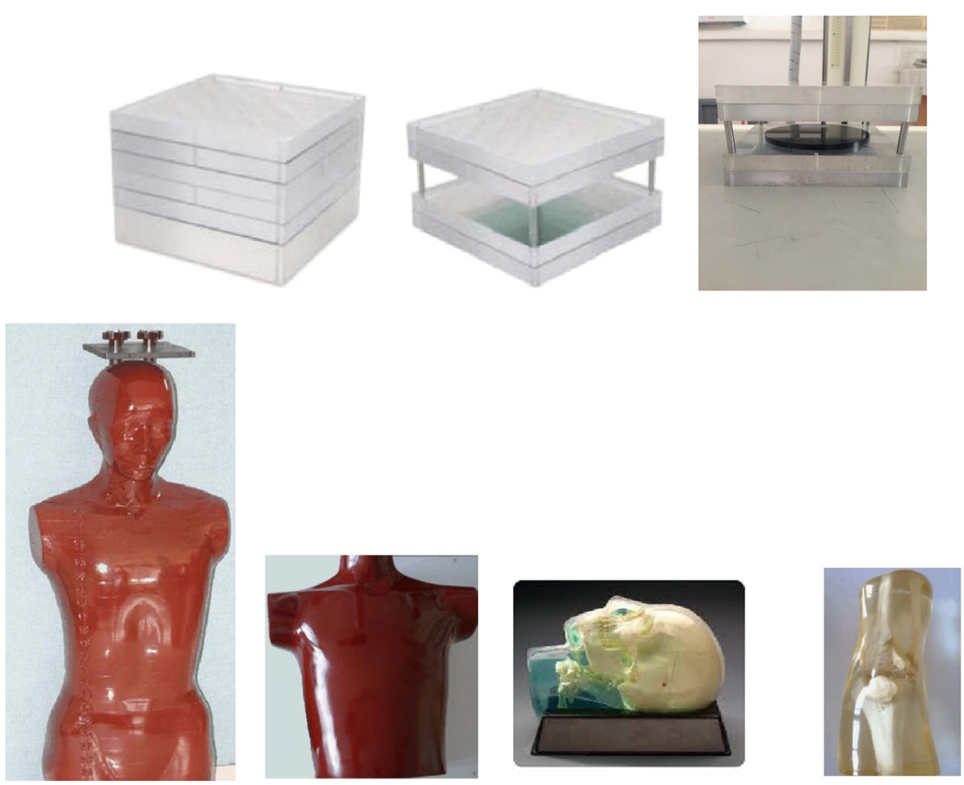

Fig. 1. Top: PMMA slab (left), ANSI chest phantom (middle) and ANSI chest with contrast test tool (right). Bottom: anthropomorphic phantoms; Rando phantom, thorax phantom, skull phantom and extremity phantom (left to right).