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Mimicking the Chest Radiograph: Patient Equivalence of the CDRH Chest Phantom with Added Insert

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Abstract

***Objective*:** To evaluate medical X-ray doses and image quality, so called phantoms that mimic particular aspects of the patient are used. The Centre for Devices and Radiological Health (CDRH) chest phantom has been used for studies of radiation exposure to the lung fields under automatic exposure (AEC) conditions. Recently, a quasi-anatomical insert was introduced to create contrast between chest organs. Direct comparison of the phantom performance with clinical chest images has not been reported previously. This study applies the phantom to conventional radiography imaging of the chest to establish its patient equivalence.

***Methods**:* Entrance doses with backscatter and chest radiographs of 77 patients were mirrored in the phantom at the same exposure factors. Optical density (OD) as well as beam transmission through the different regions of both media were also compared. A 2-sample t-test was used to test for differences while the Pearson's correlation coefficient (r) was used to test the strength of (any) linear relationship between the measured parameters in both media.

***Results*:** Results show a 13.5% difference in entrance surface doses (ESD). Beam transmission through both media showed statistically significant differences (P = 0.05). OD_{lung} was higher in CXR than the phantom images. $OD_{(lung\ +\ ribs)}$ on the CXR was not statistically different (P = 0.09) from the phantom OD_{lung}. Mean OD for the mediastinum varied by 28%. Differences are statistically significant ($P < 0.05$) in all areas except the diaphragm (P = 0.8). There is good +ve correlation in ESD and beam transmission for all regions. A weaker +ve correlation was found for OD in all areas. In both cases correlation is significant ($P < 0.05$). The phantom and CXR parameters vary linearly together, but are not of equal value.

***Conclusion*:** A linear relationship was found between measurements made with the phantom and CXR for beam transmission and for optical density. Thus the phantom can provide a useful test tool for both perceptual studies and quality assurance (QA) in chest radiography

Introduction

Effects of ionizing radiation rule out the use of human subjects for studies involving direct exposure to radiation, but have stimulated the search for substitutes, with results that can be applied to human patients with limited error. The International Commission on Radiation Units and Measurements (ICRU)[1] defines a tissue substitute as a material that is used to simulate a particular tissue relative to named physical characteristics, and depending on application. Physical characteristics of radiation interaction and dosimetric quantities at the point of interest in the body are utilised. Commercially available phantoms are expensive. Availability of more affordable and easy to use phantoms will increase their use in the radiology clinic. Such a phantom has been reported in literature [2, 3]. The LucAl (CDRH) chest phantom was developed to mimic an average adult patient with 23 cm chest thickness. Made from common and inexpensive materials Lucite and aluminium (LucAl), it has been tested for patient equivalency for various x-ray equipment and beam characteristics, and reported to be accurate in patient exposure and radiation dose studies involving chest irradiation [2]. The CDRH phantom is designed to mimic the postero-anterior (PA) projection of the chest, and can rest conveniently on the x-ray couch or any flat support leaning against the chest stand. While the CDRH phantom simulates the lung fields, the recent addition of a quasi anthropomorphic anatomical insert [4] has provided the necessary differential attenuation of the x-ray beam creating a range of contrast as is common in chest radiographs.

Purpose of study

To the best of our knowledge, there is not a lot of information on application of the LucAl phantom in the day to day quality control programmes in radiology departments. The low cost, simple design and light weight of the phantom make it attractive for everyday use in clinical settings both for dose monitoring and image quality studies. This study examines the radiographic characteristics of the LucAl CDRH phantom used with the anatomical insert, and compares these to the human chest radiograph. Establishing the patient equivalence of the phantom will both justify and encourage its everyday application in chest radiography optimization studies in diagnostic radiology.

Materials and method

Following the designs and dimensions laid out by the Food and Drug Administration, USA (FDA) [3] and Vassileva [4], the CDRH chest phantom and the anatomical insert were constructed in the departmental workshop. The chest phantom was made from perspex and aluminium, while the insert was made of perspex. Details of the design and dimensions can be found in the references [3, 4]. The insert was made to represent thoracic structures namely, the heart, diaphragm and mediastinum. The addition of the insert provides the needed differential attenuation of the chest organs.

LiF TLD-100 (3.2 x 3.2 x 0.9 mm chips) calibrated with known doses of x-rays at 70 - 120 kVp and 3 mAs were used for the study. A Rialto TLD reader was used to analyze the TLDs. A calibration factor (CF) obtained from the plot of corrected counts against dose was used to convert TLD readings in the study to dose in mGy. The variation between TLD phosphors did not exceed ± 4%. All exposures were made with Siemens Multix Pro P x-ray unit (Siemens, UK) having total filtration of 3.5mm Al equivalent. Reproducibility of the unit for both kVp and timer was better than ± 5%. Tube measurements were made with a UNFORS® type 511 calibrated radiation dosemeter (Unfors Instruments, Sweden). Kodak lanex x-omat cassettes with regular screens were used with x-ray film speed of 400. All x-ray films were processed with a Kodak x-omat multiloader 7000 autoprocessor which was monitored weekly for sensitometric compliance with acceptable clinical standards. All exposures were made with the phantom placed against the chest stand equipped with a r12, N40 grid.

TLDs were positioned on the body of the patient (or phantom) at the point of entry of the central ray to measure the entrance surface doses (ESD). ESD and transmitted beam for 77 PA chest patients attending x-ray clinic were monitored with LiF TLD -100. ESDs for the phantom were similarly determined with as many exposures as the number of patients monitored, using the same exposure factors as for the patients. Transmitted doses were obtained by attaching TLD to corresponding areas on the side of patient proximal to the x-ray film. The intensity of the transmitted beam for different patient exposure settings through the phantom and its 'anatomy' was also determined. Transmitted beam was to match the total energy fluence, including scatter, for each region of the patient to that of the phantom at the same exposure. ODs were determined for different regions of both CXR and phantom (PXR) films using an X-rite® 331 digital densitometer which had reproducibility ±3%. Densities were measured for the lung area (between the $5^{th}/6^{th}$, $6^{th}/7^{th}$ and $7^{th}/8^{th}$ ribs, respectively), on the ribs (lung + ribs) and on the image of the sternum, heart and diaphragm. Results obtained were compared for both phantom and patient using the 2 sample t-test to determine differences in the parameters measured. Linearity of (any) relationship between both media was assessed by Pearson's correlation coefficient (r) taking all tested parameters into account.

Results

Mean patient body thickness recorded in the study was 22.5 cm (range 19.3 to 25.2 cm). The CDRH phantom thickness was 23 cm. The phantom image (PXR) appears like a CXR without the ribs. Figure 1 (a, b, c and d) show the images of the chest and the phantom with their histograms, showing typical distribution of the image variables. Optical densities (ODs) on the film are higher than those on PXR. Close similarities between the two subjects are noticed in the median and modal values obtained on the histograms, while the mean and threshold values show the inherent differences. Table 1 shows mean ODs for chest and phantom films, obtained with AEC and manual selection of exposure. The 1st and 3rd quartile values of OD (AEC exposure only) for all areas of the images studied are shown in Figure 2.

Mean ESD was 0.17 ± 0.05 mGy for the patients. The phantom recorded mean ESDs of 0.19 ± 0.006 and 0.20 ±0.05 mGy for AEC and manual exposure settings, respectively. OD differences between CXR and phantom images were highest in the lung area. Densities were higher in CXR lung fields by about 29.9% for AEC exposures and 27.2% for manually selected exposures. OD values measured on the ribs ($OD_{(lung+ribs)}$ differed from the phantom lung OD by less than 4% for the images produced with AEC in place. This suggests that the CDRH phantom aggregates the optical density produced by the x-ray beam transmitted through both the soft tissue and bone of the human chest.

Mean values of OD for the heart varied by 30.5% for AEC images between the media. The sub-diaphragmatic region recorded equal mean values for both films. However, the chest films recorded a wider range of ODs (0.15 – 1.07) for the area than the phantom (0.30 – 0.35) because of patient variability. Mediastinal optical densities were significantly higher for the phantom than for the CXR. A difference of about 28% was observed between the OD of the two media for AEC images. A much higher value of 32% is observed for manually exposed films. The higher phantom mediastinal OD suggests either a higher beam transmission or higher degree of forward scatter at the region or a combination of both, when compared to CXR. This was confirmed by a 25% difference in beam transmission for the area between the two media (Figure 3). Other (AEC) beam transmission results showed a 28.3% difference for lung area, 30% for the heart and 25% for the diaphragm.

A 2-sample t-statistic showed that with the exception of beam transmission through the diaphragm ($P = 0.8$), all differences in OD and beam transmission between the media were statistically significant ($P < 0.05$). Specific p-value for the lungs was $P = 0.01$, while $P < 0.01$ was obtained for the other organs. There was good +ve correlation ($r = 0.7$) in ESD and beam transmission for all regions. A weaker +ve correlation ($r = 0.3$) was found for OD in all areas. However, in both cases correlation was statistically significant ($P < 0.05$). This implies that the radiographic parameters obtained for the phantom and CXR varied linearly together, but were not of equal values.

Discussion

Chest x-ray examinations are the most frequently performed radiological procedure. Although the dose per examination is very small, chest radiography is said to contribute significantly to the collective dose [5, 6]. It is for this reason that optimization of the radiographic technique through QA studies is essential. The phantom studied here offers tremendous opportunity for regular, easy and daily QA studies for both dose and image quality. A major radiological advantage of the phantom is the acquisition of a PA CXR image with the different thoracic organs in place. The image therefore resembles a chest radiograph without the ribs, and allows for non objective assessment of image quality by perceptibility of the anatomical structures as required in diagnostic radiology [7, 8].

The differences between patient chest radiograph and phantom films in this study reflect the characteristics of the media. While the human body carries a wide range of structures that introduce anatomical noise in the image, the phantom has very homogenous contour. Although the beam transmission is identical, the scattering and absorption properties of the two media are not, and the differences are sufficient to introduce the noted variation in radiographic parameters. For example, the ESD measured at the entry point of the beam is slightly higher for the phantom than the patients. This may be due production of greater backscatter at the surface of the phantom than of patients. The mass/electron density of LucAl is higher than tissue [9]. Equally, the effective atomic numbers of perspex and tissue are not exactly equal. The measured transmission values may therefore not truly represent the quality of the exiting beam. While both beams are hardened as they exit the object, it will be worth investigating the energy spectra of the emergent beam from the two media.

A major limitation in using the phantom for image quality assessment is in the lack of 'anatomical noise' [10] the absence of which could make object detection tasks a lot much easier than is clinically possible. Apart from this, its radiographic properties vary linearly with actual patient chest films making it a handy resource for regular quality assurance (QA) studies in any radiological department.

Conclusion

This study has highlighted an overestimation of ESD and better radiographic contrast within the energy range utilized in diagnostic radiology by the CDRH chest phantom with an insert first introduced by Vassileva [4]. The attenuation properties of the homogenous material used in making the phantom generally produced lower optical densities than were expected on human chest films. Despite these differences, a linear relationship was found between measurements made with the phantom and CXR for beam transmission and for optical density. Thus the phantom can provide a useful test tool for both perceptual studies and quality assurance (QA) in chest radiography

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Fig. 1a: Phantom image with insert

Fig. 1b: Normal chest radiograph

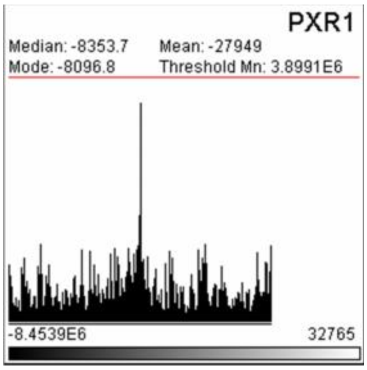

Figure 1c: Histogram of phantom image

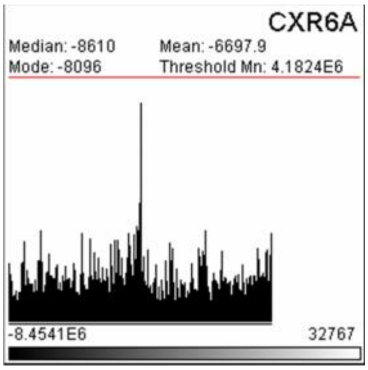

Figure 1d: Histogram of CXR

Figure1: Phantom radiographic image (a) Chest radiograph (b) and their histograms (c) and (d), respectively. The histograms show small differences in image contrast which was better for the phantom than the CXRs because of the absence of anatomical noise in the phantom.

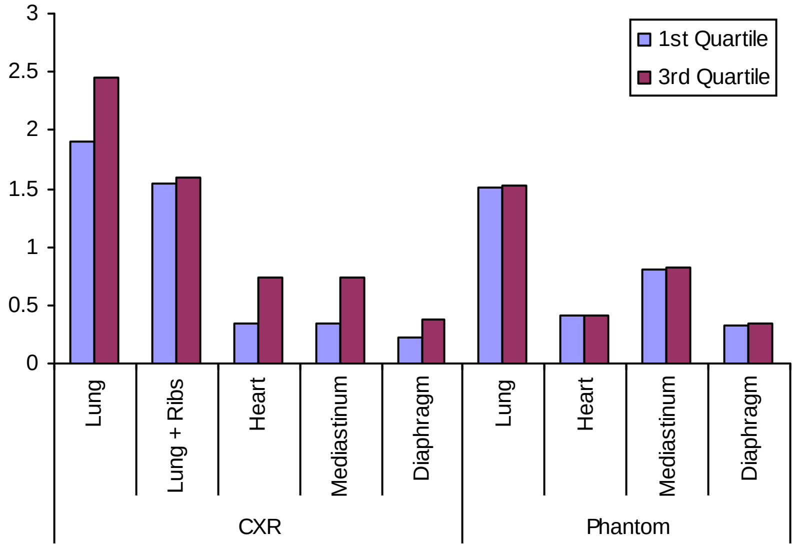

Figure 2: 1st and 3rd quartile OD values for patient Chest and Phantom films

Table 1: Optical density (OD) values measured for different anatomical areas

Projection	OD lung	OD(lung + ribs)	OD heart	OD mediastinum	OD diaphragm
Patient data	2.17 (0.3)	1.58 (0.07)	0.59 (0.3)	0.58 (0.3)	0.34 (0.2)
Phantom (AEC)	1.52 (0.01)		0.41 (0.007)	0.81 (0.01)	0.33 (0.01)
Phantom (*Manual)	1.58 (0.02)		0.42 (0.006)	0.85 (0.02)	0.34 (0.009)

* Manual exposure selection with AEC off

Variation in OD could be due to many factors, patient, film batch differences, exposure differences, etc.

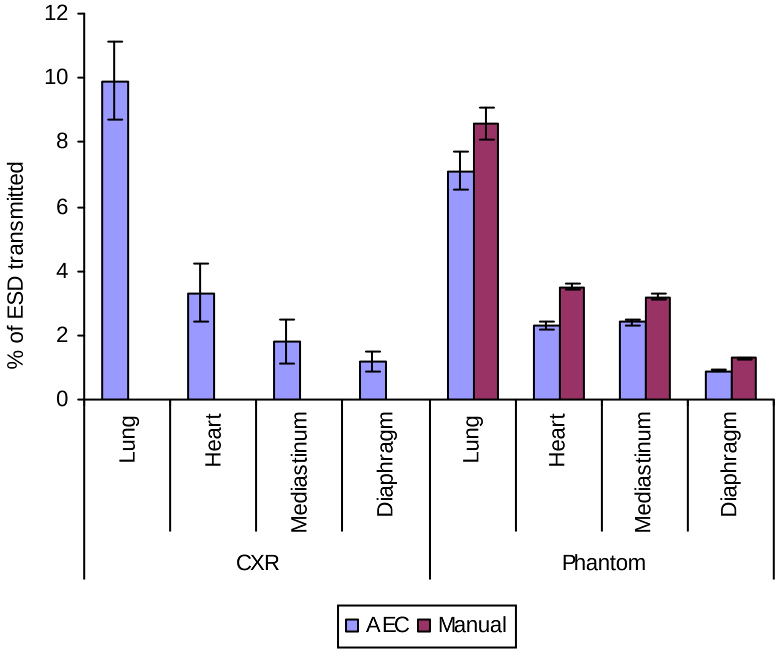

Figure 3: Comparison of transmitted beam intensities for patients' chest x-ray and phantom with 'anatomical' insert in place. Error bars are one standard deviation from the mean values.