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Chest radiography doses with film screen: Is further reduction possible?

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Abstract

In order to establish the possibility and extent of further dose reduction in film screen chest radiography, gelatine based test objects were used in a simple chest phantom to obtain images at the current chest dose (D_{ref}) and at percent dose reduction of 41, 65 and 77, respectively. Images studied by human observers to assess clarity and detectability of lesions (obtained from the perceptibility scores and number of lesions seen, respectively), showed that doses below 0.1 mGy (about 40% reduction from D_{ref}), but not exceeding 0.06 mGy (65% reduction from D_{ref}), may be achieved in conventional film/screen chest radiography.

Keywords

kilovoltage, optical density, scattered radiation

Introduction

Conventional radiography is still heavily used across the world. In the United Kingdom (UK) it forms over 60 % of all radiology examinations [1]. As a result of the high frequency, the need to control the radiation doses received by patients in chest radiography has produced dose reduction of almost half of the values achieved in the UK, in the mid 1980s [2,3]. Current practice has not revealed any debilitating effect of these low doses on image quality. However, since the review of doses is a continuing process, it is necessary to examine the effects of further reduction from the current dose levels on image quality, with a view to determine how much lower such reduction can be extended without significant loss in image quality.

In the current study the effects of dose reduction (by increasing kVp) on chest radiography image quality are studied by observer perceptibility of objects in a phantom. Many radiology centres have adopted the high kVp technique for chest radiography. This technique is used to extend dose reduction below current UK reference dose levels and to assess phantom chest images produced on film. Image quality is defined by object clarity (assessed by the observer scores for objects seen) and objects detectability (assessed by the number of objects seen). Considering the reduced film latitude at high kVp, this study will help define approximate lower dose limits for dose reduction in film screen (FS) chest radiography. The information obtained would be valid in economies that are still heavily dependent on film screen technology.

Materials and methods

The chest phantom designed by the Centre for Devices in Radiological Health (CDRH), incorporating a quasi anatomical insert first proposed by Vassileva [4] was used in the study. Test objects made of gelatine, a known tissue substitute [5], were positioned in the phantom to simulate lung and mediastinal lesions [6].

Forty lesions were positioned in the lung area and 24 on the mediastinal region of the phantom. The diameter of lesions/blobs studied was 5 mm, chosen for convenience. Also, considering the homogeneous background of the phantom, 5 mm lesion size was assumed to be sufficient for the intended purpose. The positions of the lesions were randomly altered between exposures to reduce the tendency for the occurrence of observer 'familiarity' during viewing.

Dose reduction and irradiation

Exposures were made with a Siemens Multix Pro x-ray tube, having total tube filtration equivalent to 3.5 mm of aluminium and 0.1 mm copper (Cu), in an x-ray room equipped with a chest stand and grid (r12, N40), as well as a table top or x-ray couch with a 35 x 35 cm film. Kodak Lanex x-omat cassettes with regular (400 speed) screens were used to store the films before exposure. For irradiation, the chest phantom was positioned on a trolley against a chest stand simulating a typical posterior-anterior (PA) chest examination. This position was maintained for all exposures to avoid variations in the automatic exposure control (AEC) and dose received.

For irradiation, the exposure factors were set to obtain the current mean entrance skin dose (ESD), taken as the reference dose (D_{ref}) determined with a factory calibrated Unfors Xi meter. Initial tests were carried out with chest doses reduced by increasing kVp from 102-150 under automatic exposure control (AEC), to determine dose points with significant perceptible differences in image quality from D_{ref}. As a result, (0.17) D_{ref} and three other dose points, 0.10, 0.06 and 0.04 mGy, were selected for the study. The doses, the corresponding kVps, and the percent dose reduction at which they were obtained, are shown in Table 1. The kVps used in the study were chosen against the background that small changes in kVp settings give results that are not statistically different from each other [7]. The choice of AEC in this study was informed by availability although the results will be tested under manual exposure conditions in another study. In all, three exposures were made per dose and each observer completed three reading sessions. The team of observers was made up of medical physicists with wide ranging experiences in image interpretation and quality studies. Reading sessions varied in time, ranging from 24 hours to a week. There were no restrictions on reading distance,

Table 1: Doses used in the study

Parameter	Values			
kVp	102	117	133	150
Dose (mGy)	**0.17***	0.10	0.06	0.04
% reduction	-	41.2	64.7	76.5

** Current ESD for chest (radiography) in place of study*

though the average measured reading distance was 28.8 ± 6.0 cm. Viewing conditions were optimised following recommended standards [8, 9].

Assessment of image quality

From these sessions, mean results, within and intra reader consistencies were determined. Image quality was assessed by observer perceptibility of the 40 (lung) and 24 (mediastinum) lesions in the phantom images following the method of ranked scoring. Ranked scoring allows for qualitative assessment and relates to the observers' level of confidence, similar to clinical practice [10], quantification of the degree of perceptibility [11]. This has been widely used in image quality studies [12-14].

Observers were not aware of the doses used in the irradiation process but were instructed on the shapes of the objects to be studied. An explanation of the ranking system was also given. Observers viewed and scored images according to a pre-selected scale which defined the degree of certainty with which a conclusion was made. Scores ranked from 0 - 3; with the interpretation as: 0 (not seen); 1 (barely seen); 2 (seen but not clear); and 3 (clearly seen). Trial assessments were necessary to ensure observer compliance with the requirements of the process. They were asked to indicate as many objects as they could possibly detect on each radiograph. Observers scored all images seen on a score chart made of a schematic drawing of the phantom. From this the scores relative to the lesions being studied were extracted.

Intra-reader consistency over the three reading sessions was determined from the reliability analysis using SPSS statistical software. Values of Cronbach alpha were accepted at 0.6 or higher. Between reader agreement was assessed with the intraclass correlation coefficient (ICC) also using the SPSS software version 14 (SPSS inc. Chicago, Illinois, USA), which indicated threshold values of statistical significance. ICC values of 0 imply agreement due to chance, while 1 meant perfect agreement [15]. Interpretation of observer agreement from ICC values was poor to fair (0 - 0.4), moderate (0.41 - 0.6), excellent (0.61 - 0.8) and almost perfect (0.81 - 1) [16]. Differences between results obtained at Dref and the test doses were studied with the student T-statistic at the 95% confidence interval.

Results

The mean results for image clarity and lesion detectability are as shown in Figures 1 and 2, respectively. The results followed the expected trend of lower lesion clarity at lower doses. Dose reduction produced no statistically significant differences in the observer scores between D_{ref} and 0.10 mGy (P = 0.07). Statistically significant differences were however noted at doses below 0.10 mGy (0.06 and 0.04 mGy) for the lung area. Lesion perceptibility scores or clarity for the mediastinal region showed a similar pattern with statistically significant differences ($P < 0.05$) observed at 0.06 mGy.

Statistical analysis confirmed significant differences (P = 0.01) between the number of lesions seen at D_{ref} and lesions seen at 0.06 mGy, for the lung fields. In the mediastinal region, there was a statistically significant difference (P = 0.03) between the number of lesions seen at D_{ref} and at 0.10 mGy. Detectability values at the doses 0.06 and 0.04 mGy were also significantly different from D_{ref}.

The above results show that the dose for the onset of loss of image clarity in the mediastinum was lower (0.06 mGy) than that for the onset of

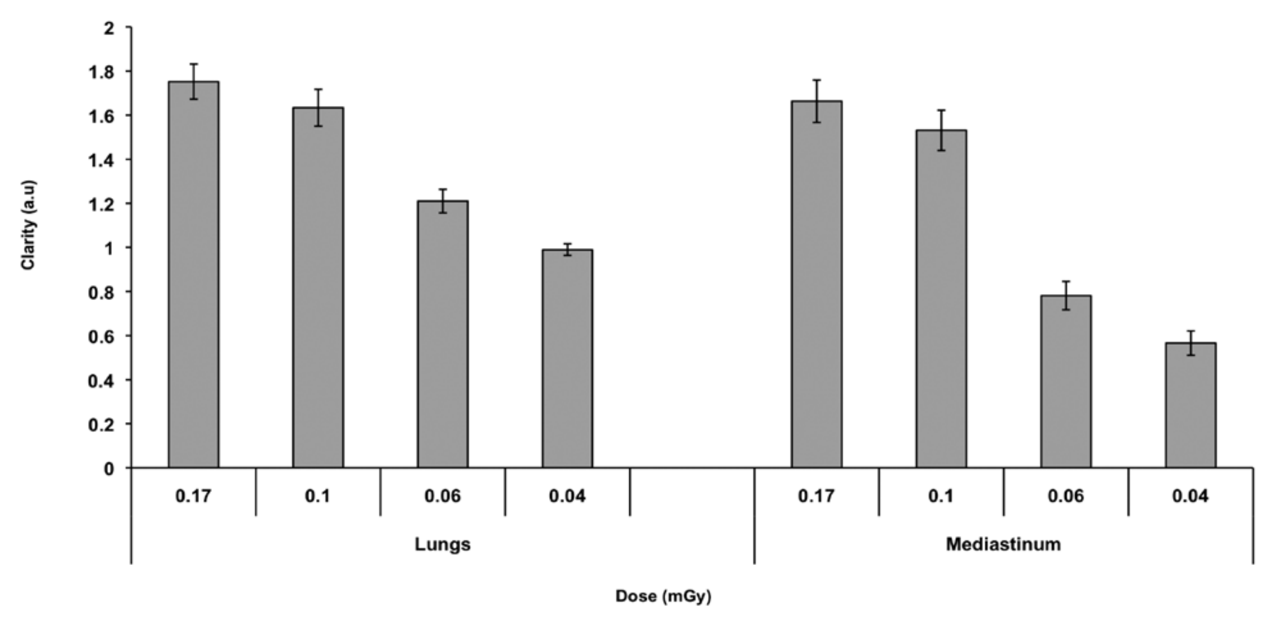

*Figure 1: Clarity of the perceived lesion images with dose reduction in the lung and mediastinal areas of the chest phantom. Errors are Standard error of the mean. * Result significantly different from D_{ref}. (a.u. is arbitrary unit)*

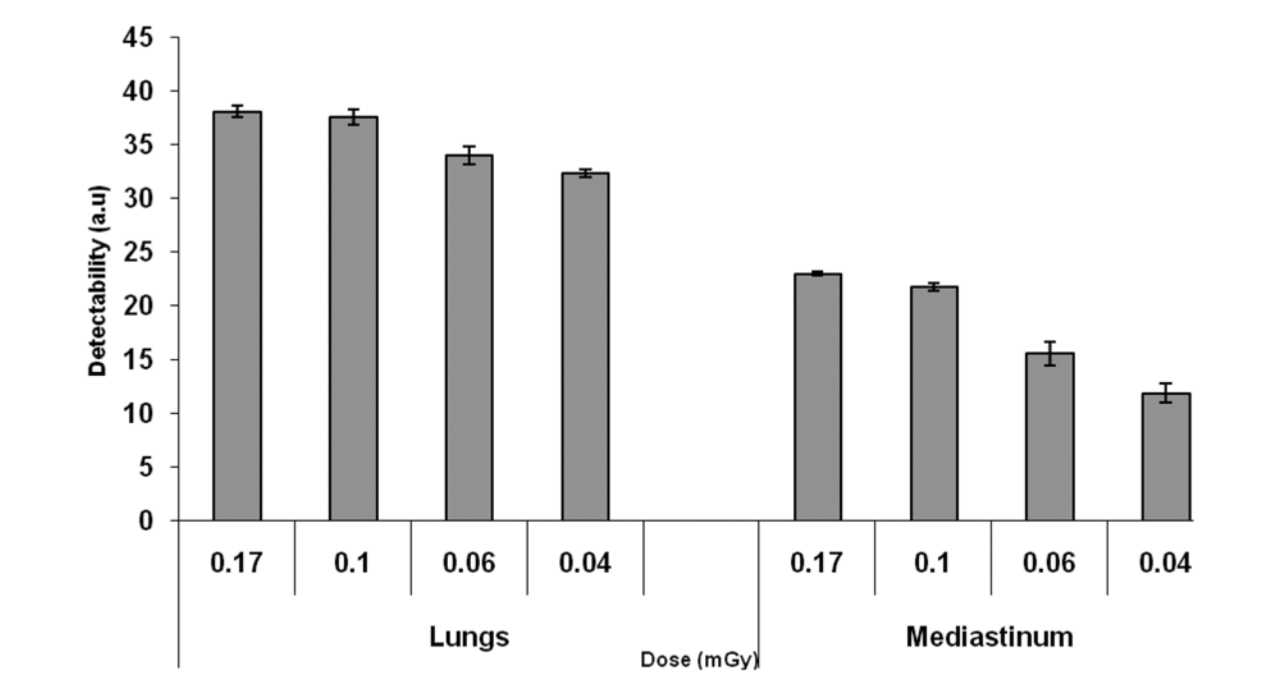

*Figure 2: Detectability of lesion images with dose reduction in the lung and mediastinal areas of the chest phantom. Errors are standard error of the mean. * Results significantly different from D_{ref}. (a.u. is arbitrary unit).*

detectability (0.10 mGy). This may imply that observers probably overrated the clarity of images since no defined standard image was used.

Within reader consistency was good at a mean Cronbach alpha value of 0.91 (range 0.78 - 0.98). Inter-observer agreement varied from poor to moderate as indicated by the ICC results. A mean ICC value of 0.18 with a range of 0.04 to 0.60 was obtained. These results were statistically significant ($p < 0.05$).

Discussion

This study has outlined changes in image clarity and detectability with dose reduction below the current dose levels applied in chest radiography. Although these criteria, namely clarity (mean perceptibility score) and detectability (number of lesions seen), are closely related, their difference lies in the fact that an object might be present (detectable) in an image but not be sufficiently defined (lacking in detail or clarity) to be confidently and correctly interpreted. Information about the onset of loss in image clarity and detectability will be useful in defining dose reduction limits for the selected projections in the current study.

Average observer results in the current study show that as dose was reduced there was eventually some deterioration in image quality with both assessed parameters. It was observed that a 64.7% reduction in dose from D_{ref} produced significant loss in both clarity and detectability in the lung area. Dose reduction by up to 41.2% (0.10 mGy) did not produce significant changes in image quality. It follows that a dose reduction above 40% but less than 65% from the current dose level can be achieved without significant change in image quality.

In the mediastinum, loss of image clarity was observed at 0.10 mGy, but detectability required dose reduction up to 0.06 mGy for significant results to be observed. This suggests that further reduction of conventional chest radiography doses may produce images which are lacking in clarity even when the objects may be detectable by the observer. The implication of this is that interpretation of such images may be made with reduced observer confidence.

The results obtained in this study confirm the report of Sandborg and colleagues [17], which suggest that lower contrast produced in FSR at higher kVps reduce scores in FSR chest image visual grading analysis (VGA).

Notwithstanding the parameter adopted for assessment, clarity or detectability, dose reduction produced poorer image quality (IQ) results. One reason for this could be the increased scatter radiation produced as a result of the method of dose reduction used. Increased kVp, while decreasing the dose for the same optical density (OD), increases secondary radiation or scatter in the forward direction. The contribution of this 'extra' irradiation source to the image actually degrades it. Increased kVp may also have produced over-penetration of the lesions resulting in poor subject contrast.

At high photon energies, such as were used in the current study, Compton interaction dominates and the contrast produced depends solely on differences in tissue (object) densities [9]. Apart from this, the x-ray film has a limited range of useful sensitivity or dynamic range to radiation [18]. Thus the use of high kVp technique can only be applied as far as the range of exposures to which the film is sensitive, that is, within the useful part of the characteristic curve. This implies that the use of high kVp as a dose reduction measure must be balanced by the attainment of expected results of images of sufficient diagnostic quality to counter the increase in organ doses as a result of increased penetration.

These results may be useful in providing a platform for determining a cut-off point for dose reduction in chest radiography in centres using the conventional film screen system. Between the current dose level D_{ref} and other doses, there is statistical evidence to accept the differences in perceived lesions per dose. Generally, while this work shows that doses in conventional chest radiography could be further reduced by kVp increase to 0.10 mGy, it is evident that reduction below 0.06 mGy may be counter productive. These results appear to agree with the work of Compagnone and colleagues [19] who reported chest radiography doses of 0.07 mGy in a clinical study, citing diagnostically acceptable images at this dose.

These results could be used to define lower limits of dose reduction in FS chest radiography after wide range clinical trials. However, whether the adoption of such lower limits would be supported by other dose reduction techniques and film-screen speeds is a subject for further research. In addition, the application of these results to other commonly detected pulmonary patterns like reticular patterns, cysts and ground glass patterns is to be further investigated.

Conclusion

Dose reduction, using current dose levels as targets, and image quality in FSR has been studied by observer perceptibility of test objects in chest radiography using a phantom. The results show loss of both clarity and detectability as doses were further lowered. These results imply that imaging of pathologies which are small and round, such as small cell cancers, may yield limited diagnostic information when doses lower than 40 % of current dose levels in conventional chest radiography are employed in FSR. These results can, with further clinical confirmation, form the basis for defining lower limits of dose reduction by kVp increase in chest radiography.

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