Achievable Radiation Dose Reduction with Comparable Image Quality in Chest Radiography

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ABSTRACT

Objective: Chest radiography is one of the commonest radiological investigations utilised in various medical specialties. Although the radiation dose of a single chest radiography to the patient is relatively low, the contribution of the accumulated dose is substantial due to its frequent use in medical diagnoses. Optimisation of radiation dose and image quality, therefore, remains a challenging area in research and routine practice. The objective of this study was to evaluate the radiation dose in chest radiographs (CXR) taken with a sensitivity value of 400 (as in factory setting) and to perform quality assessment of the diagnostic applicability of dose-reduced CXRs obtained with a higher sensitivity value (of 600).

Methods: CXRs performed in 100 consecutive adult patients attending a regional hospital in Hong Kong were reviewed. Images were taken with a sensitivity value of either 400 or 600 by an Agfa 85X CR System. Fifty patients were allocated to each acquisition technique and the assignment of this grouping was random. No significant mismatch with respect to patient body size was noted in the two groups. Diagnostic reference levels, estimated with dose area product derived from exposure measurements, were used to quantify the radiation dose. The difference in radiation dose between these two sets of images was statistically evaluated by the Student’s t test. The CXRs were reviewed and rated by two independent radiologists in random order. The image quality of CXRs was assessed by 10 criteria as stated in the European Guidelines On Quality Criteria for Diagnostic Radiographic Images. Differences in image quality ratings between the two acquisition techniques were statistically quantified by analysis of variance with repeated measures. The agreement ratio for each criterion between the two radiologists was calculated. Evaluation of the interobserver agreement for the overall mean score of image quality was performed using weighted Cohen’s Kappa statistics.

Results: A statistically significant reduction in radiation dose of 32.8% (p<0.001) by using image acquisition technique with sensitivity 600 (mean dose area product = 10.00 cGycm²) was noted as compared with the CXR taken with sensitivity 400 (mean dose area product = 14.87 cGycm²). Concerning the image quality of the radiographs, a high level of interobserver agreement was demonstrated in most of the criteria (range, 82.7%-100%). The Kappa score for the overall mean score of image quality between the two raters was 0.547, signifying moderate and clinically acceptable interobserver agreement. No statistically significant difference was noted in the overall mean image quality between the two sets of CXRs taken with different sensitivity values and radiation doses (p = 0.106). Both groups of CXRs showed satisfactory diagnostic applicability for medical practice.

Conclusion: The radiation dose in CXRs obtained with sensitivity 600 was shown to be effectively reduced while maintaining sufficient image quality compared with those taken with sensitivity 400. This setting is recommended for future standard CXR acquisition. Extension of similar clinical audit and quality assurance studies to radiographs of other body regions will be helpful to ensure adherence to the principles of radiation protection.

Key Words: Clinical audit; Radiation; Radiography, interventional; Radiography, thoracic
INTRODUCTION

Chest radiography is one of the most utilised imaging investigations involving radiation performed across many medical specialties, and remains the mainstay of chest imaging despite the known diagnostic superiority and increasing availability of cross-sectional techniques. As stated by Schaefer-Prokop et al., chest radiography is responsible for approximately 30% to 40% of all X-ray examinations performed. An upright chest radiograph (CXR) is a fast and essential tool to rule out various chest diseases and cardiac congestion or to monitor response to therapy. Although the radiation dose of a single CXR to the patient is relatively low, the contribution of the accumulated dose is substantial due to its frequent use in medical diagnoses. Optimisation of radiation dose and image quality, therefore, remains a challenging area in research and routine practice.\(^2\)

In recent years, computed radiography systems are widely used due to their compatibility with existing radiographic equipment and ability to produce images comparable in quality with conventional screen-film combinations. Evaluation of their performance as a replacement for the conventional screen-film system is important for quality assessment.

Radiation protection is a major concern for the patients and staff employed in radiological services. The application of ‘as low as reasonably achievable’ (ALARA) principle to minimise the stochastic radiation risk is essential to control the potential hazardous effect on patients and medical personnel involved in the procedure.\(^3,4\)

In 1990, the International Commission on Radiological
Radiation Dose Reduction in Chest Radiography

Protection (ICRP) first suggested the use of diagnostic reference levels (DRLs) for optimisation of dose and radiation protection. DRLs were further recommended in greater detail in 1996, with the aim of avoiding excessive radiation dose that does not contribute towards additional clinical information. It is also used to assess the dose impact after introduction of new systems or protocols.

Many professional and regulatory organisations, including the ICRP, American College of Radiology, American Association of Physicists in Medicine, UK Health Protection Agency, International Atomic Energy Agency, and European Commission endorse the use of DRL and impose their application in daily clinical practice. Reference levels are usually set at the 75th percentile of the dose distribution surveyed across a nation or area, and considerable variations have been seen in different regions and countries. The use of DRL has been shown to reduce the overall dose used in clinical practice. This was demonstrated in the National Health services of the UK.

It is important to ensure that image quality is not compromised while reducing the radiation dose as that may have a deterrent effect on clinical practice and patient care. Image quality must satisfy the requirements for making a correct diagnosis at the lowest possible level of radiation exposure. Low-dose imaging of poor quality will not be deemed acceptable for clinical use and will lead to unjustified radiation exposure. Consequently, optimisation of radiation dose in chest radiography is crucial in radiological services.

A previously published study showed that different exposure class and sensitivity of an Agfa computed radiography system could be used to optimise chest radiography resulting in a lower radiation dose using higher sensitivity parameters; however, clinical verification was not well established.

Therefore, the objective of this study was to evaluate the radiation dose in CXRs taken with a sensitivity value of 400 (as in factory setting) and to perform quality assessment of the diagnostic applicability of dose-reduced CXRs obtained with a higher sensitivity value (of 600).

METHODS
Approval for the study was obtained from the local ethics committee (Clinical Research Ethics Review Committee of the Hospital Authority, Hong Kong).

Study Group
CXR of 100 consecutive adult patients attending a regional hospital in Hong Kong were reviewed. A total of 45 male and 55 female patients were recruited. The age of patients ranged from 19 to 93 years, with a mean age of 57.5 years. Paediatric patients (aged <18 years) were excluded from the study. All CXRs were taken with justified clinical indications. The images were obtained with a sensitivity value of either 400 or 600 by an Agfa 85X CR System (Agfa, Mortsel, Belgium). Fifty patients were allocated to each acquisition technique and the assignment of this grouping was random. No significant mismatch with respect to patient body size was noted in the two groups.

Image Acquisition
The Agfa 85X CR system with cassette MD-40 general and reader in combination with a ceiling-mounted X-ray tube was used. All CXRs were postero-anterior CXRs obtained with patients in an upright position. They were obtained with the same tube system using the high-kilovoltage technique at 125 kVp with automatic exposure control. The displayed exposure values in milliampere-second varied according to patients’ weights and constitution. Film-focus distance was set at 180 cm. A sensitivity of either 400 or 600 was used.

DRLs, estimated with dose area product (DAP) derived from exposure measurements, were used to quantify the radiation dose. The DAP for each CXR was documented and compared with the latest DRL data in the UK.

Image Evaluation
All the CXRs were assessed using a dedicated picture archiving and communication system (PACS) equipped with high-resolution LCD monitors and Carestream viewing software. The CXRs were reviewed and rated by two independent radiologists in a random order. All the images were masked for any patient clinical information and acquisition parameters. Reading conditions were standardised and kept constant throughout the reading session. Image processing tools, including windowing or magnification, were allowed as per the preference of the radiologists.

The image quality of CXRs was assessed by 10 criteria stated in the European Guidelines On Quality Criteria
for Diagnostic Radiographic Images. The image quality criteria referred to characteristic features of the imaged anatomical structures with a specific degree of visibility. One mark was given if the criterion was fulfilled while zero mark was given if it was not fulfilled. All images were individually assessed and the total score for each CXR was calculated.

**Statistical Analysis**

**Assessment of Radiation Dose**

The difference in radiation dose between the two sets of images (sensitivity 400 and 600) was statistically evaluated by the Student’s t-test.

**Subjective Assessment of Image Quality**

Differences of image quality ratings between the two acquisition techniques were statistically quantified by analysis of variance (ANOVA) with repeated measures.

**Interobserver Agreement**

The interobserver agreement was calculated to check the reliability of the image quality evaluation by two independent radiologists and determine the impact of image quality on diagnostic performance.

The agreement ratio for different criteria was calculated. A good correlation indicated that the scores of the two observers could be combined to obtain a mean score for the image quality parameters.

Interobserver agreement for the overall mean score of image quality was quantified using weighted Cohen Kappa statistics. The Kappa values were interpreted by the guideline suggested by Altman: values <0.20, poor; 0.21-0.40, fair; 0.41-0.60, moderate; 0.61-0.80, good; and 0.81-1.00, very good. Calculations were performed by the Statistical Package for the Social Sciences (Windows version 19; SPSS Inc, Chicago [IL], US).

The hypothesis of the study was that dose-reduced CXRs using a higher sensitivity (of 600) could provide images of diagnostic quality that are applicable for patient management, which may reduce the radiation exposure to patients.

**RESULTS**

CXR s taken with sensitivity 400 (n = 50) and 600 (n = 50) were compared; the results are listed in Table 1. A significant reduction in radiation dose of 32.8% (p<0.001) by using image acquisition technique with sensitivity 600 (mean DAP = 10.00 cGycm²) was noted as compared with the CXRs taken with sensitivity 400 (mean DAP = 14.87 cGycm²).

Concerning the image quality of the radiographs, a high level of interobserver agreement ratio was demonstrated in most of the criteria (ranging from 82.7% to 100%),

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Table 1. Exposure and dose measurements for chest radiographs obtained with sensitivity value of 400 and 600.

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>Sensitivity</th>
</tr>
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<tbody>
<tr>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>50</td>
<td>600</td>
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<table>
<thead>
<tr>
<th>Exposure (mAs)</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.36</td>
<td>400</td>
</tr>
<tr>
<td>1.58</td>
<td>600</td>
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</table>

<table>
<thead>
<tr>
<th>Exposure (mAs)</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.72-3.76</td>
<td>400</td>
</tr>
<tr>
<td>1.27-2.20</td>
<td>600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DAP mean (cGycm²)</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.87</td>
<td>400</td>
</tr>
<tr>
<td>10.00</td>
<td>600</td>
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</table>

<table>
<thead>
<tr>
<th>DAP range (cGycm²)</th>
<th>Sensitivity</th>
</tr>
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<tbody>
<tr>
<td>10.10-26.90</td>
<td>400</td>
</tr>
<tr>
<td>7.20-15.00</td>
<td>600</td>
</tr>
</tbody>
</table>

Abbreviation: DAP = dose area product.

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Table 2. Agreement ratio between the two raters for each image quality criterion as referenced by the European Guidelines On Quality Criteria for Diagnostic Radiographic Images.

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Details*</th>
<th>Interobserver agreement ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Chest X-ray performed at full inspiration (6 anterior ribs or 10 posterior ribs above diaphragm)</td>
<td>96.9</td>
</tr>
<tr>
<td>2</td>
<td>Symmetrical reproduction of thorax (spinosus process located between the medial ends of clavicles)</td>
<td>82.7</td>
</tr>
<tr>
<td>3</td>
<td>Medial border of scapulae outside of lung fields</td>
<td>83.7</td>
</tr>
<tr>
<td>4</td>
<td>Reproduction of whole rib cage above diaphragm</td>
<td>98.0</td>
</tr>
<tr>
<td>5</td>
<td>Visually sharp reproduction of vascular pattern in lungs, especially for peripheral vessels</td>
<td>100.0</td>
</tr>
<tr>
<td>6</td>
<td>Visually sharp reproduction of trachea and proximal bronchi</td>
<td>90.8</td>
</tr>
<tr>
<td>7</td>
<td>Visually sharp reproduction of borders of heart and aorta</td>
<td>98.0</td>
</tr>
<tr>
<td>8</td>
<td>Visually sharp reproduction of diaphragm and lateral costophrenic angles</td>
<td>99.0</td>
</tr>
<tr>
<td>9</td>
<td>Visualisation of retrocardiac lung and mediastinum</td>
<td>100.0</td>
</tr>
<tr>
<td>10</td>
<td>Visualisation of spine through heart shadow</td>
<td>100.0</td>
</tr>
</tbody>
</table>

* Visualisation = features are detectable but details are not fully reproduced; reproduction = details are visible but not necessarily clearly defined; visually sharp reproduction = details are clearly defined.
indicating that the individual scores could be combined into an average value (Table 2; Figures 1-3). The Kappa score between the two raters was 0.547, signifying moderate and clinically acceptable interobserver agreement.

Criteria 1 to 4 were excluded from the analysis as they mainly depended on the positioning of patients during image acquisition and were not directly related to the use of different radiation doses. Possible minimum score was 0 and the maximum score was 6. Details of the overall mean image quality ratings are listed in Table 3. ANOVA with repeated measures showed that there was no statistically significant difference in the overall mean image quality between the two sets of CXRs taken with different sensitivities and radiation doses ($p = 0.106$). Both groups of CXRs showed satisfactory diagnostic applicability for medical practice.

**Table 3.** Mean image quality ratings of chest radiographs with sensitivities 400 and 600.

<table>
<thead>
<tr>
<th>Chest X-ray sensitivity</th>
<th>Mean image quality rating by radiologist A</th>
<th>Mean image quality rating by radiologist B</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>5.86</td>
<td>5.98</td>
</tr>
<tr>
<td>600</td>
<td>5.82</td>
<td>5.84</td>
</tr>
</tbody>
</table>
DISCUSSION
Digital chest radiography with an integrated PACS is shown to provide more advantages than conventional film-screen radiography.\(^\text{18,19}\) Digital images offer instant image display, wide dynamic range, and linear signal response; and are flexible in processing and archiving.\(^\text{18,20,21}\) The introduction of digital radiography has revolutionised communication between radiologists and clinicians, improved image quality and reduced radiation exposure of patients.\(^\text{1}\) However, there are potential risks of unnoticed increased patient dose because increased dose no longer leads to overexposed films. In addition, the automatic optimisation of image contrast and density renders it impossible to determine if a radiograph is overexposed or underexposed by judging its density alone. Suboptimal image processing may also lead to suppression of diagnostic information.\(^\text{1}\) Therefore, evaluation of the radiation dose and performance of computed radiography in terms of image quality is important for quality assessment of digital chest radiography used as a replacement for the conventional screen-film system.

Computed radiography systems are based on storage phosphor technology. These can be cassette-based and portable, or integrated into a dedicated Bucky system for chest radiography.\(^\text{1}\) Computed radiography can be acquired with different sensitivities, and it has been shown that the lower the sensitivity value used, the better the image quality achieved at the expense of higher radiation dose.\(^\text{14}\) Thus, maintaining a balance is crucial, and images of satisfactory diagnostic applicability should be obtained at the lowest possible radiation dose.

According to the ICRP, radiation protection should be based on three major principles: justification, optimisation, and application of dose limits.\(^\text{22}\) The use of radiation should be supported by valid clinical indications that will benefit the patients, and influence the efficacy of diagnosis and patient management. In addition, the information obtained by imaging should not be achievable with other methods with lower risks, and the selected imaging procedure should be reliable and reproducible with sufficient sensitivity, specificity, accuracy, and predictive value to the clinical question.\(^\text{15}\)

Dose optimisation is performed via three aspects: diagnostic quality, radiation dose (entrance surface dose at the point of intersection of X-ray beam axis with the surface of standard-size adult patient, including backscatter radiation), and the choice of radiographic technique.\(^\text{15}\) According to the ALARA principle, the image quality required is determined by the clinical question that has to be answered. What constitutes an ‘adequate image quality’ remains controversial and studies are usually performed with respect to a reference guideline. In our study, the European Guidelines On Quality Criteria for Diagnostic Radiographic Images were used as a well-established reference for rating of image quality.\(^\text{15}\) A high agreement ratio between two independent raters with a clinically acceptable interobserver agreement was noted, validating the use of this guideline in the assessment of image quality for CXR.

Our results highlight a substantial reduction in the dose of CXRs taken with a higher sensitivity (sensitivity 600) while maintaining sufficient image quality as rated by the image quality criteria guideline. For CXRs taken with sensitivity 400, there was an excessive 48.7% of radiation dose compared with the latest DRL data in the UK,\(^\text{10}\) which is clearly not desirable. However, with the change of sensitivity parameter to 600, the dose level shows a 32.8% reduction and becomes comparable with DRL in the UK.

Based on data from this study, it is recommended to perform chest radiography using sensitivity 600 instead of 400 to develop clinically acceptable images with lower radiation dose. This clinical audit is in line with the concept of DRL introduced by the ICRP, which states that investigations should be carried out for dose values consistently exceeding the DRL.

Although small sample size was a limitation of this study, it serves the purpose of a pilot study evaluating the impact of sensitivity parameter on radiation dose and image quality. Studies with larger samples and extending to radiographs of other body regions will be useful in further clinical audits and quality assurance programmes.

CONCLUSION
The radiation dose in CXRs obtained with sensitivity 600 was shown to be effectively reduced while maintaining sufficient image quality versus those taken with sensitivity 400. This setting is recommended for future standard CXR acquisition. Extension of similar clinical audit and quality assurance studies to radiographs of other body regions will be helpful to ensure adherence to the principles of radiation protection.
Radiation Dose Reduction in Chest Radiography

protection.

DECLARATION
No conflicts of interests were declared by authors.

REFERENCES