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ORIGINAL ARTICLE

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 radiograph (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 $cGycm^2$) was noted as compared with the CXR taken with sensitivity 400 (mean dose area product = 14.87 $cGycm^2$). 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*

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中文摘要

成人胸部X光片可達至圖像質素相近但輻射劑量較低

尹宇瀚、施美虹、賴銘曦、朱志揚、鄧業勤、陳德文、邱麗珊

目的：胸部X光檢查是用於各種醫學專科的一種常見放射學檢查。雖然病人接受單一次的胸部X光檢查所受的輻射劑量相對較低，但由於此技術在醫學診斷經常使用，病人累積的輻射劑量較大。因此輻射劑量和圖像質量的最佳比例在研究和常規運用中成為一項挑戰。本研究旨在評估靈敏度值設為400（即出廠設置）時所拍胸部X光片（CXR）的輻射劑量，並完成靈敏度值提高至600以致輻射劑量減少時所拍CXR用於診斷的質量評估。

方法：回顧香港一所分區醫院連續100名成年患者的CXR，圖像由Agfa 85X CR系統拍攝，靈敏度值設置為400或600。所有患者隨機分組，50名患者被分配接受兩種拍攝技術之一種。兩組病人在體型方面並無顯著差異。利用曝光測量得出的劑量面積乘積估算診斷參考水平，再以參考水平量化輻射劑量。用學生*t*測試來評估兩組所釋放的放射劑量的差異。由兩名獨立的放射科醫生分別隨機審查，然後以歐洲指南中診斷性放射圖像質量標準的十項評分標準為CXR評分。利用重複量數變異數分析把兩種設置之間圖像質量的差異統計量化，計算出兩名放射科醫生在每項評分標準的符合率。採用加權Cohen's Kappaа統計評估圖像質量總平均分的觀察者間一致性。

結果：與靈敏度400（即平均劑量面積乘積＝14.87 $cGycm^2$）比較，採用靈敏度600（即平均劑量面積乘積＝10.00 $cGycm^2$）所釋放的放射劑量明顯減少了32.8%（$p<0.001$）。平片圖像質量方面，觀察者間在大多數評分標準上達到高一致性（介乎82.7%至100%）。圖像質量總平均分方面，Kappa系數為0.547，代表觀察者間符合率為中等，臨床尚可接受。兩組不同靈敏度設置及放射劑量的CXR的總平均圖像質量並無統計學顯著差異（$p=0.106$）。兩組CXR均顯示滿意的臨床診斷適用性。

結論：與靈敏度400相比，採用靈敏度600所得出的圖像質量相若，但可有效降低所釋放的輻射劑量。所以推薦採用靈敏度600的設定拍攝標準CXR。把類似的臨床審核和質量保證研究擴展至其他身體部位的X光片有助確保遵守輻射防護的原則。

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,[1] 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

Protection (ICRP) first suggested the use of diagnostic reference levels (DRLs) for optimisation of dose and radiation protection.[5] DRLs were further recommended in greater detail in 1996,[6] 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.[7-10]

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.[11] 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.[12,13]

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.[14]

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

CXRs 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.[10]

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.[15] 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.[16]

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[17]: 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.

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

	Sensitivity	
	400	600
No. of patients	50	50
kVp	125	125
Exposure (mAs) mean	2.36	1.58
Exposure (mAs) range	1.72-3.76	1.27-2.20
DAP mean (cGycm^2)	14.87	10.00
DAP range (cGycm^2)	10.10-26.90	7.20-15.00

Abbreviation: DAP = dose area product.

RESULTS

CXRs 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 cGycm^2) was noted as compared with the CXRs taken with sensitivity 400 (mean DAP = 14.87 cGycm^2).

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%),

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.[15]

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

* 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.

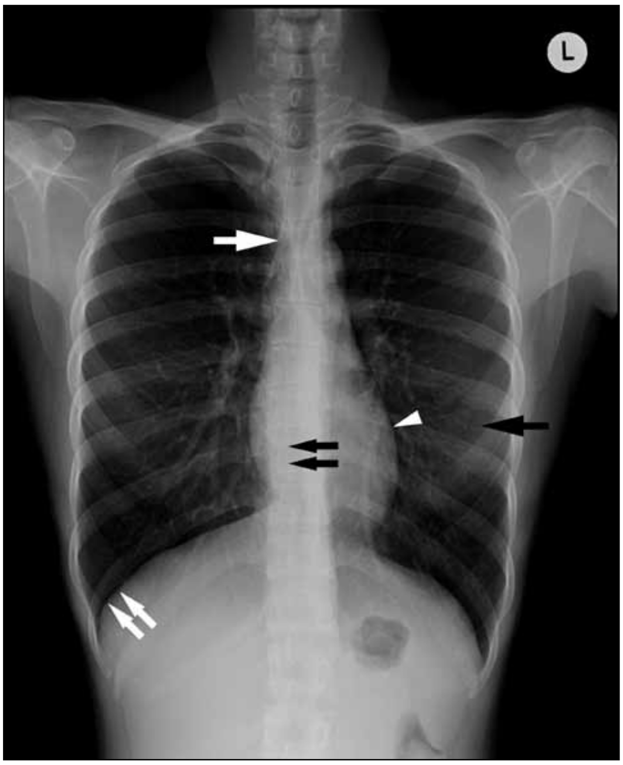

Figure 1. A chest radiograph of a Chinese adult fulfilling several criteria stated in the European Guidelines On Quality Criteria for Diagnostic Radiographic Images: visually sharp reproduction of vascular pattern in lungs, especially for peripheral vessels (single black arrow); visually sharp reproduction of trachea and proximal bronchi (single white arrow); visually sharp reproduction of diaphragm and lateral costophrenic angles (double white arrow); visualisation of spine through heart shadow (double black arrow); and visually sharp reproduction of left heart border (white arrowhead).

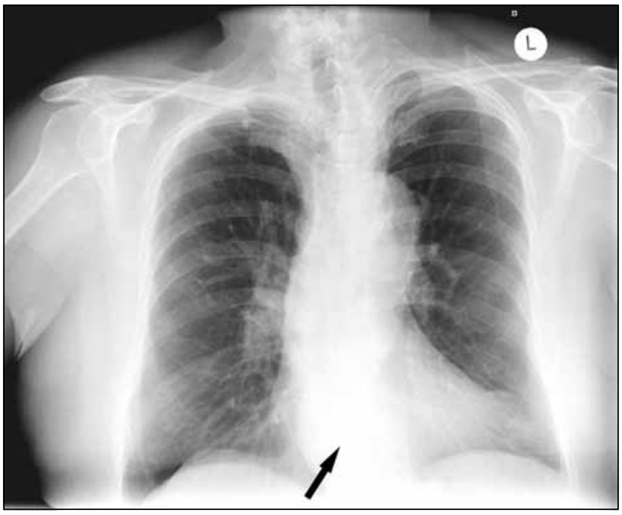

Figure 2. A chest radiograph of a Chinese adult that failed to fulfill the criteria of visualisation of spine through heart shadow (arrow) as stated in the European Guidelines On Quality Criteria for Diagnostic Radiographic Images.

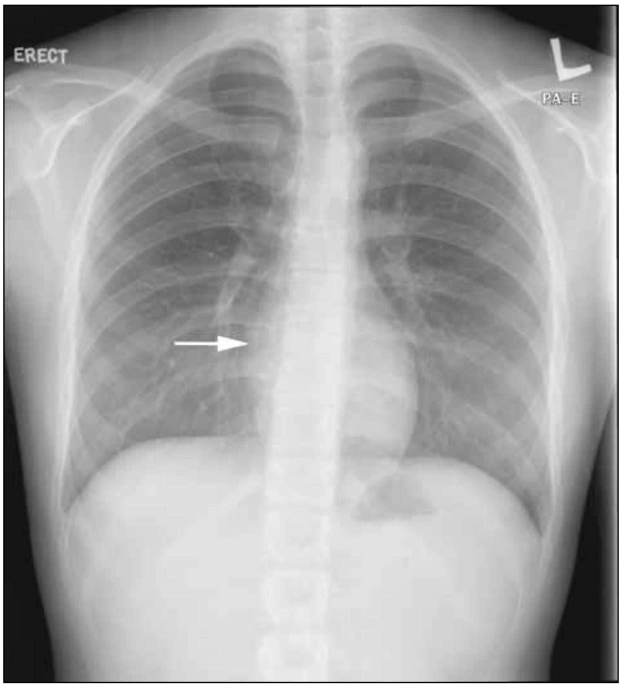

Figure 3. A chest radiograph of a Chinese adult that failed to fulfill a criterion in the European Guidelines On Quality Criteria for Diagnostic Radiographic Images: there is no visually sharp reproduction of the right heart border (arrow).

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

Chest X-ray sensitivity	Mean image quality rating by radiologist A	Mean image quality rating by radiologist B
400	5.86	5.98
600	5.82	5.84

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.

DISCUSSION

Digital chest radiography with an integrated PACS is shown to provide more advantages than conventional film-screen radiography.[18,19] Digital images offer instant image display, wide dynamic range, and linear signal response; and are flexible in processing and archiving.[18,20,21] The introduction of digital radiography has revolutionised communication between radiologists and clinicians, improved image quality and reduced radiation exposure of patients.[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.[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.[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.[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.[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.[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.[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.[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,[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.

DECLARATION

No conflicts of interests were declared by authors.

REFERENCES

1. Schaefer-Prokop C, Neitzel U, Venema HW, Uffmann M, Prokop M. Digital chest radiography: an update on modern technology, dose containment and control of image quality. Eur Radiol. 2008;18:1818-30. cross ref
2. Veldkamp WJ, Kroft LJ, Geleijns J. Dose and perceived image quality in chest radiography. Eur J Radiol. 2009;72:209-17. cross ref
3. Vano E. ICRP recommendations on 'Managing patient dose in digital radiology'. Radiat Prot Dosimetry. 2005;114:126-30. cross ref
4. Busch HP, Faulkner K. Image quality and dose management in digital radiography: a new paradigm for optimisation. Radiat Prot Dosimetry. 2005;117:143-7. cross ref
5. 1990 Recommendations of the International Commission on Radiological Protection (Report 60). Ann ICRP. 1991;21:1-201.
6. Radiological protection and safety in medicine. A report of the International Commission on Radiological Protection (Report 73). Annals ICRP. 1996;26:1-31.
7. International Atomic Energy Agency. Optimization of the radiological protection of patients undergoing radiography, fluoroscopy and computed tomography. Vienna: IAEA; 2004.
8. European Commission. Guidance on diagnostic reference levels for medical exposures. Radiation protection 109. Luxembourg: Office for Official Publications of the European Communities; 1999.
9. Gray JE, Archer BR, Butler PF, Hobbs BB, Mettler FA Jr, Pizzutiello RJ Jr, et al. Reference values for diagnostic radiology: application and impact. Radiology. 2005;235:354-8. cross ref
10. Hart D, Hillier MC, Shrimpton PC. Doses to patients from radiographic and fluoroscopic X-ray imaging procedures in the UK-2010 review. Didcot, UK: Health Protection Agency; 2012.
11. Matthews K, Brennan PC. The Application of Diagnostic Reference Levels: General Principles and an Irish Perspective. Radiography. 2009;15:171-8. cross ref
12. Hart D, Wall BF. UK population dose from medical X-ray examinations. Eur J Radiol. 2004;50:285-91. cross ref
13. Shrimpton PC, Wall BF, Hart D. Diagnostic medical exposures in the U.K. Appl Radiat Isot. 1999;50:261-9. cross ref
14. Moore CS, Saunderson JR, Beavis AW. Investigating the exposure class of a computed radiography system for optimisation of physical image quality for chest radiography. Br J Radiol. 2009;82:705-10. cross ref
15. Carmichael JH, Maccia C, Moores BM, Oestmann JW, Schibilla H, Teunen D, et al, editors. European guidelines on quality criteria for diagnostic radiographic images. Luxembourg: Office for Official Publications of the European Communities; 1996.
16. Bankier AA, Levine D, Halpern EF, Kressel HY. Consensus interpretation in imaging research: is there a better way? Radiology. 2010;257:14-7. cross ref
17. Altman DG. Practical statistics for medical research. London: Chapman & Hall/CRC; 1991. p 404.
18. Bacher K, Smeets P, Bonnarens K, De Hauwere A, Verstraete K, Thierens H. Dose reduction in patients undergoing chest imaging: digital amorphous silicon flat-panel detector radiography versus conventional film-screen radiography and phosphor-based computed radiography. AJR Am J Roentgenol. 2003;181:923-9. cross ref
19. Schaefer-Prokop C, Uffmann M, Eisenhuber E, Prokop M. Digital radiography of the chest: detector techniques and performance parameters. J Thorac Imaging 2003;18:124-37. cross ref
20. Chotas HG, Dobbins JT 3rd, Ravin CE. Principles of digital radiography with large-area electronically readable detectors: a review of the basics. Radiology. 1999;210:595-9. cross ref
21. Kotter E, Langer M. Digital radiography with large-area flat-panel detectors. Eur Radiol. 2002;12:2562-70. cross ref
22. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP publication 103. Ann ICRP. 2007;37:1-332.