Feasibility of low-dose chest radiography with low tube potential

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Authors: K. Kim, B. W. Choi; Seoul/KR
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Aims and objectives

Chest radiograph is one of the most widely used x-ray examination. During 2006, total chest radiograph was performed 12,883,042 times in South Korea[1]. The radiation dose of a single chest radiograph is not critical. But, considering repetitive exams of the hospitalized patients and acts as a screening test, overall radiation dose by chest radiograph is not negligible at national level.

Digital radiography(DR) system has a broad dynamic range, a high detective quantum efficiency (DQE) and an ability to do post-processing, archiving and transfer of data. Low dose radiography can be possible due to these advantages. As conventional film-screen radiography system has been replaced by DR system, a new paradigm for dose management has emerged. The new strategy of DR system is ALARA principle (As Low As Reasonably Achievable). It means that image shoud be acquired at a lowest dose keeping its diagnostic performance. [2]

Previous study revealed that the overall image quality and the visibility of anatomic structures in chest radiographs obtained with lower kilovoltage(90kVp) at a same effective patient dose is better than those in other chest radiographs obtained with higher kilovoltage (121 and 150kVp) [3]. However, chest radiographs with low-voltage setting are not yet widely used. In specialized medical centers of South Korea, the average tube voltage setting of chest radiographs was 114kVp. Most of these medical centers used voltage setting of 120kVp [1].

One step further in these study, our study was designed to reduce the radiation dose without degradation of diagnostic performance. We assume that if a chest radiography is obtained with a proper low tube voltage(kVp) and a low tube current exposure time product(mAs), its diagnostic performance is acceptable with a relatively diminished radiation dose.

Automatic exposure control(AEC) is a radiographic density control device that terminates the exposure when a predetermined amount of radiation has been reached. This systems control kVp and mA as well as exposure time [4]. By lowering predetermined amount of radiation, we can reduce the radiation dose of chest radiograph.

We studied to determine the feasibility of low dose chest radiography with a lower tube potential and a lower set of AEC without degradation of image quality.
Methods and materials

Patient's selection

Thirty-six patients were prospectively enrolled in this study who met our inclusion criteria: Older than 20 years and the ability to undergo posteroanterior chest radiography in the upright position.

Written informed consent was obtained from all patients. The study protocol was approved by the institutional internal review board (ethics committee) of the University of Yonsei Medical college. Uncooperative patients or pregnant women were excluded. The age, sex, and body mass index (BMI) of each patient were recorded.

Chest radiograph procedure

All images were obtained on the same digital radiography system (REX-850R-S 800mA/150kVp, LISTEM, WONJU, 2005) with a thallium-doped cesium iodide flat-panel-detector unit (FDX4343R; TOSHIBA, Japan). The size of the detector area of the flat-panel unit was 43 43.9cm and the pixel pitch was 143 143µm. Source to image-receptor distance was 1.8m. 1mm aluminium filter was used as x-ray filter. Grid ratio was 8:1.

Phantom study

We performed a chest phantom study to find the proper AEC setting.

The tube voltage was set to 120 kVp or 90kVp and the AEC setting was adjusted to 0, -1 and -2.

Posteroanterior chest radiography was performed with each set value. We recorded the tube voltage (kVp) and dose area product (DAP) for each image. Effective patient dose (mSv) was calculated by using Monte Carlo simulations software, PCXMC which was developed by STUK, the radiation and nuclear safety authority in Finland [5]. The results showed that the lowest effective dose was obtained when the tube voltage was set to 90kVp and the AEC was set to -2. Based on this result, we determined 90kVp and -2 AEC setting by the low-dose and low-voltage setting (Table 1).

Human study
Thirty-six patients underwent posteroanterior chest radiography twice consecutively in a day; first with the standard setting (120 kVp, AEC setting : 0) and second with the low-dose and low-voltage setting (90 kVp, AEC setting : -2).

We recorded the tube voltage (kVp) and dose area product (DAP) for each image and effective patient dose (mSv) was calculated by using Monte Carlo simulations software, PCXMC.

**Evaluating method.**

All chest radiographs were read by two radiologists using the Picture Arching and Communicating System (PACS) (GE, RA1000, USA). One reader (B.W.C) was board-certificated radiologist with thirty three-year of experience in chest radiography and another reader (K.W.K) was second-year radiology resident.

All chest radiographs were randomly given assess numbers, so the evaluators were blind to the patient's clinical data and examination setting. The evaluators can adjust their own optimal viewing conditions by using PACS function : panning, zooming, inversion and windowing.

Two readers evaluated the image quality of chest radiographs by rating the visibility of thirteen different anatomic structures using a five-point grading system. A five-point scale for the visibility is given below ; Grade 5 = Excellent, Grade 4 = good, Grade 3 = moderate, Grade 2 = poor, Grade 1 = unacceptable. And thirteen anatomic structures which were rated are given below ; (1) the lung parenchyma without rib superimposition, (2) the lung parenchyma with rib superimposition, (3) the perihilar vessels, (4) the peripheral vessels (within a 2-cm-wide subpleural space), (5) the costophrenic angle, (6) the cardiophrenic angle, (7) the retrocardiac area, (8) the carina, (9) the heart contours, (10) the lower thoracic spine, (11) lung apices, (12) Right paratracheal line, and (13) Aortic arch. The readers are asked to grade only regions of normal opacity. If there was abnormal opacity in Right lung parenchyma, they were grade the lung parenchyma for the left side. But all of the chest radiographs had no visible abnormal lung lesion.

**Statistical Analysis**

Differences in age between the male and female patients were assessed by using the t test. We used a level of significance of P # .05.

The overall visibility score, the score for 13 anatomic structures and the effective patient dose were recorded for each observer, each radiation dose setting and each image. Each reader's rating data was evaluated separately. The statistical differences between the
two radiation dose settings with regard to the grade of the visibility of anatomic structures and the effective dose were evaluated by using the Wilcoxon signed rank test.

Subgroup analyses were performed: A high BMI group (higher than the median BMI) and a low BMI group (lower than the median BMI). The Wilcoxon signed rank test was also used for evaluating the statistical differences.

Data were analyzed using SPSS version 20.0 (SPSS Inc., Chicago, 2011).
Fig. 1: (Table 1: Exposure parameters for the two tube voltage and AEC setting levels used to obtain posteroanterior chest radiographs in phantom study)

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Results

Patient data

The patient group consisted of 21 men and 15 women. The mean age was 30.4 years ± 12.9. There was significant difference between the mean age of the men and that of the women. (32.7 years ± 13.4 for men and 27.2 years ± 11.7 for women, p=0.00)

The mean BMI of the patients was 22.3 ± 1.8 kg/m². The median BMI was 22.25 kg/m². The mean BMI of a high BMI group was 23.7 ± 1.0 kg/m² and the mean BMI of a low BMI group was 21.0 ± 1.2 kg/m².

Visibility score of anatomic structures.

Two radiologist’s overall visibility scores of the low-dose setting images and the standard-dose setting images were not significantly different respectively (48.50±4.01 & 48.81±2.86; 35.42±2.91 & 35.47±3.06, p>.05)(Table 2). Each visibility scores were not significantly different in most of the anatomic structures. But some anatomic structures shows difference of the delineation : the carina (3.17 & 3.44) and the right paratracheal line (3.44 & 3.72) in one radiologist(B.W.C) and the lung parenchyma without rib superimposition (2.72 & 3.06) and the retrocardiac area (3.11 & 2.64) in another radiologist(K.W.K).

For the subgroup of patients (n = 18) with a BMI greater than and the subgroup of patients (n = 18) with a BMI less than the median BMI (22.25 kg/m2), the overall visibility scores of the low-dose setting images and the standard-dose setting images were not significantly different. In high BMI group, the visibility scores of the perihilar vessels (3.17 & 3.56) and the right paratracheal line (3.28 & 3.61) in one radiologist(B.W.C) and the retrocardiac area (3.00 & 2.50) in another radiologist(K.W.K) were significantly different (p<.05).

In low BMI group, the visibility scores of the lung parenchyma without rib superimposition (2.67 & 3.06, the retrocardiac area (3.22 & 2.78) and the right paratracheal line (2.78 & 2.45) in one radiologist(K.W.K) were significantly different (p<.05).

Radiation dose

The average effective dose of the low-dose setting was reduced by 34.8% compared with that of the standard-dose setting (26.9±6.7 μSv, 41.3±9.1μSv)(Table 3).
In subgroup analyses, similar results were noted. The average effective dose of the low-dose setting was reduced by 32.3% in high BMI group and 37.7% in low BMI group compared with that of the standard dose setting (High BMI group: 29.3±7.5 µSv, 43.3±6.9 µSv, Low BMI group: 24.4±5.0 µSv, 39.1±1.1 µSv).
Fig. 2: (Table 2 : Averaged overall visibility score)

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Fig. 3: (Table 3: Averaged effective dose)

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Conclusion

The results of image analysis show that the average effective dose could be reduced without significant degradation of overall visibility score of anatomic structures by applying the low-dose setting. Although the average scores of each reader are significantly different, this interobserver variation did not affect the scores of the low-dose setting images and the standard-dose setting images.

Some anatomic structures of the standard-dose setting images received a significantly higher visibility score than those of the low-dose setting images; the carina and the right paratracheal line in one radiologist(B.W.C) and the lung parenchyma without rib superimposition in another radiologist(K.W.K). And the retrocardiac area of the low-dose setting images received a significantly higher visibility score than that of the standard-dose setting images in one radiologist(K.W.K). Despite these differences, most of the anatomic structures received similar scores in both images. And between the two radiologists had no common anatomic structures received a significantly different visibility score.

In previous study of simulated nodule detection, dose reduction led to degradation of observer's detectability of mediastinal simulated nodules, but not in lung nodules[6]. Our study did not show correlated results. The low-dose setting images were graded higher in retrocardiac area and lower in the lung parenchyma without rib superimposition in one radiologist.

The BMI subgroup analyses show the similar results. For two dose settings, overall visibility score of anatomic structures were not significantly different in the high BMI group and the low BMI group. But this subgroup analyses bear a limitation. The patient's BMI ranged from 18.49 to 25.65 kg/m2 in our study. Most of the patients are normal-weight people and only three patients are overweight. Because of this population configuration, no discernable difference of body weight was seen between two groups. By replacing the standard dose setting with the low-dose setting, the average affective dose was markedly decreased(34.8%). Excessive dose reduction could reduce diagnostic performance of chest radiograph. Stephan Metz et al [7] demonstrated that reduced detector dose could be a cause of decreased diagnostic performance in an anthropomorphic chest phantom study. And Kroft LJ et al [8] suggested that a 50% dose reduction seems feasible in digital chest radiography, whereas further dose reduction reduces the diagnostic quality. Considering these study, an adequate amount of dose reduction was achieved in our study.

Because of the broad dynamic range, digital radiography system can be relatively free from underexposure or overexposure[9]. In addition, by using PACS function like adjusting window width and level, radiologists can get enough contrast in the area that they want to evaluate. This function is not available in film-screening system. In previous articles that underwent image quality assessment, the hard-copy format was
used[2, 3, 7, 8]. In one study, when using PACS system compared to using hard-copy format, sensitivity can be further increased without falling diagnostic accuracy [10]. When considering the above points, use of digital radiography system and PACS can be assumed that this helped to maintain the visibility of the anatomic structures.

There are some limitations in this study. First, The visibility score of anatomic structures does not solely represent the diagnostic performance of the chest radiography. There is no evidence of linear correlation between a visibility of anatomic structures and a lesion detectability and our five point grading system is based on observer's subjective preference. Further validation studies based on our results will be required.

Second, the magnitude of the reduction in the effective patient dose was relatively small. The absolute value of the reduced effective patient dose by low-dose setting was about 14.0µSv. In ICRP 2007 recommendation, the recommended annual dose limit for the general population is 1mSv(Patient effective dose)[11]. Compared with this advisory level, the effective of decreasing the effective dose in this study is negligible. But, as mentioned above, considering the total number of chest radiography performed over the year, overall radiation dose by chest radiograph is not negligible.

Third, there is a selection bias in our study. Unintentionally, most of the our subjects are young people. This factor might be associated with lung status and BMI. But in our study, we focused on comparisons between two chest radiographs of a same patient. It was expected that the characteristics of study population are not cause a significant effect on the results.

In conclusion, by using 90 kVp and low AEC setting, low-dose chest radiography was feasible where the effective patient dose could be remarkably reduced while maintaining image quality.