# Radiation Exposure by Routine Radiographic Examinations: Multicenter Study in Japan with Thermoluminescence Dosimetry and Estimation from the Radiographic Data

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## INTRODUCTION

X-ray examinations are commonly used in health care and, in most developed countries, they represent the largest man-made source of radiation exposure for the population. The need for standardization of radiation exposures has been suggested and the guidance levels for various radiographic and radioisotope examinations has been proposed by the International Atomic Energy Agency (IAEA) as a Safety Standard (1). The guidance levels by IAEA are based on European studies (2-4). In many countries, the situation of medical radiographic exposures in each country should be researched before the appropriate guidance level is established. This study was conducted to research radiation exposures by routine x-ray examinations in the major hospitals in Japan. Five types of simple radiography were selected on the basis of their prevalence in the clinical medical practice; the posteroanterior (PA) chest, anteroposterior (AP) abdomen, AP pelvis, and AP and lateral (LAT) lumbar spine. The radiation dose was estimated by a calculation method based on the radiographic data. In a limited number of hospitals, thermoluminescent dosimeters (TLDs) were also used to measure the entrance surface dose of the patients and compared with the results from the calculation method.

## MATERIALS and METHODS

### Calculation Method

A questionnaire survey was carried out at 295 hospitals registered as training facilities of Japan Radiological Society. Conditions of the x-ray systems were recorded; type of radiography (computed radiography or film-screen system), type of rectification (single phase, three phase or inverter type), filtration (mmAl equivalent), source-to-image distance, type of exposure control (automatic or manual), with or without use of grid and grid ratio. The body thickness, x-ray tube kilovoltage, tube current and exposure time (mAs), use of supplementary filter and film size were recorded in non-selected five-each patients for five types of examination; PA chest, AP abdomen, AP pelvis, and AP and LAT lumbar spine. Entrance surface doses were estimated using Non Dosimeter Dosimetry-M (NDD-M) method originally designed by Mori (5). This method is based on the theory of Birch (6); a process of computing theoretical x-ray spectra for any filtration, target angle and tube voltage between 30 and 150 kV. The NDD-M factors (5) are computed for rectifiers of single phase, three phase and inverter type, tube voltage between 40 and 150kV, and filtration between 1.5 and 9.0 mmAl. Linear interpolation program implemented in a Microsoft Excel® was used for computation of the NDD-M factors for clinically recorded conditions. Entrance surface dose was calculated as the following formula.

$D = \text{NDD-M}(f) \times \text{mAs} \times (1/\text{FSD})^2$
D: entrance surface dose (mGy)
NDD-M(f): NDD-M factor
mAs: tube current (mA) x exposure time (second)
FSD: film-to-skin distance (m)

The statistical analysis was performed with a commercially available software package (Stat View® Ver 5). The normality of distribution of dose for each part was rejected at $p<0.0001$ level by the Kolmogorov-Smirnov one-sample test .

### Direct Measurement

Direct measurement of the patients' entrance surface doses was performed using thermoluminescent dosimeters (TLDs) for the 5 types of radiographic examination at 13 university hospitals. MSO-S TLDs (Kyokko, Tokyo) were mailed to the hospitals and one each TLD was placed on the patient's skin at the center of the radiation field when the radiography was taken. Measurement was performed in five each patient for each type of radiograph, then the TLDs were returned for read out. Calibration and read out of all TLDs were undergone by one of the authors (SI).

# RESULTS

## Calculation Method

The questionnaire was returned from 193 hospitals out of 295 (withdrawal rate, 65.4%), and the data of 772 to 863 radiographs for each type of examination (total, 4047 radiographs) were obtained. Table 1 summarizes the results for the 5 types of radiography compared with the IAEA guidance levels (1). The third-quartile (75-percentile) value of the estimated dose was; chest 0.19 mGy, abdomen 3.1 mGy, pelvis 2.8 mGy, AP and lateral lumbar spine 4.3 and 11.5 mGy, respectively. These doses corresponded to 47% (chest), 31% (abdomen), 28% (pelvis), 43% (AP lumbar spine) and 38% (LAT lumbar spine) of the IAEA guidance levels.

Table 1. Entrance surface doses (mGy) estimated by the calculation method in comparison with the IAEA guidance levels.

| Type of Radiography | No. of Cases | Mean | SD | Median | 3rd Quartile | IAEA Guidance level |
|---|---|---|---|---|---|---|
| Chest | 772 | 0.16 | 0.11 | 0.13 | 0.19 | 0.4 |
| Abdomen | 863 | 2.29 | 1.82 | 1.83 | 3.07 | 10 |
| Pelvis | 792 | 2.33 | 1.43 | 1.98 | 2.78 | 10 |
| Lumbar spine | | | | | | |
| AP | 818 | 3.73 | 2.70 | 3.02 | 4.32 | 10 |
| LAT | 802 | 9.28 | 5.93 | 7.97 | 11.5 | 30 |

The histograms of radiation dose in five types of radiography are shown in Fig. 1- 5.

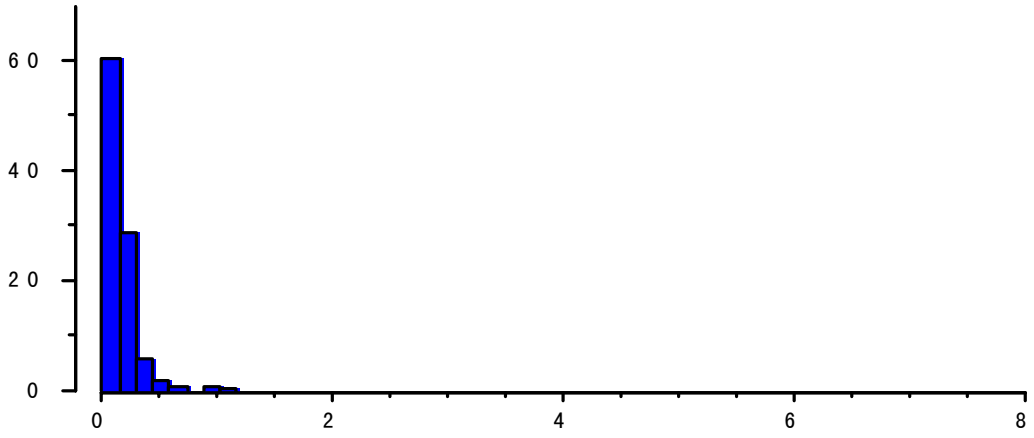



Figure 1. x= PA Chest, Skin dose (mGy), y= Percentile
(n=665, min= 0.009mGy, max= 7.282mGy)

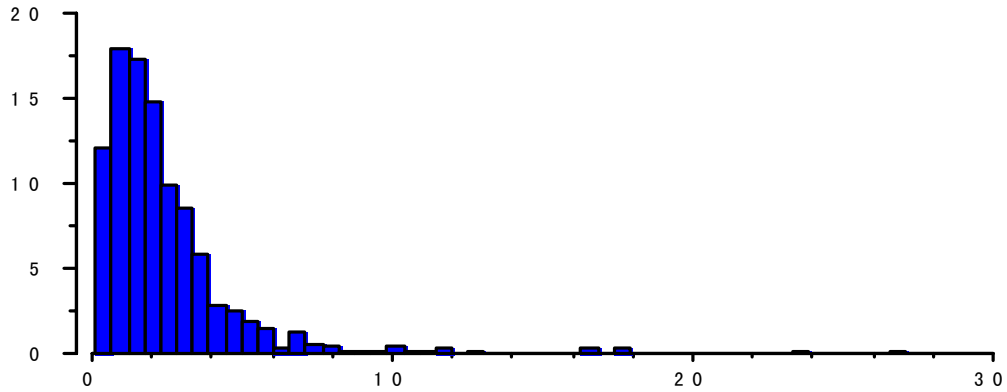



Figure 2. x= AP Abdomen, Skin dose (mGy), y=Percentile
(n=735, min=0.124mGy, max=27.075mGy)

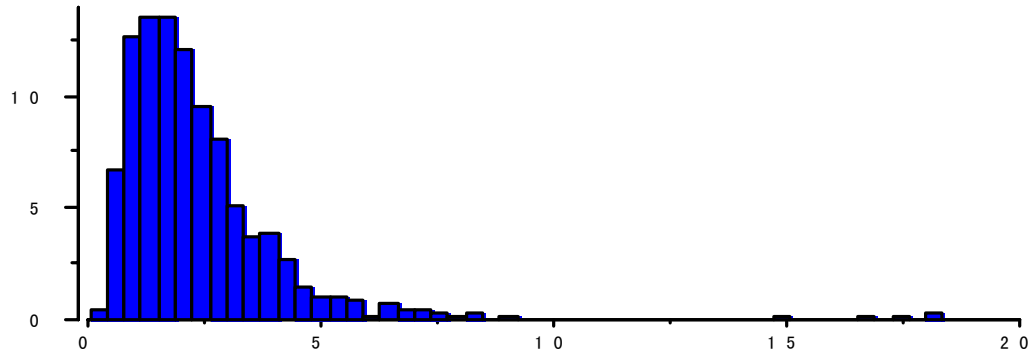
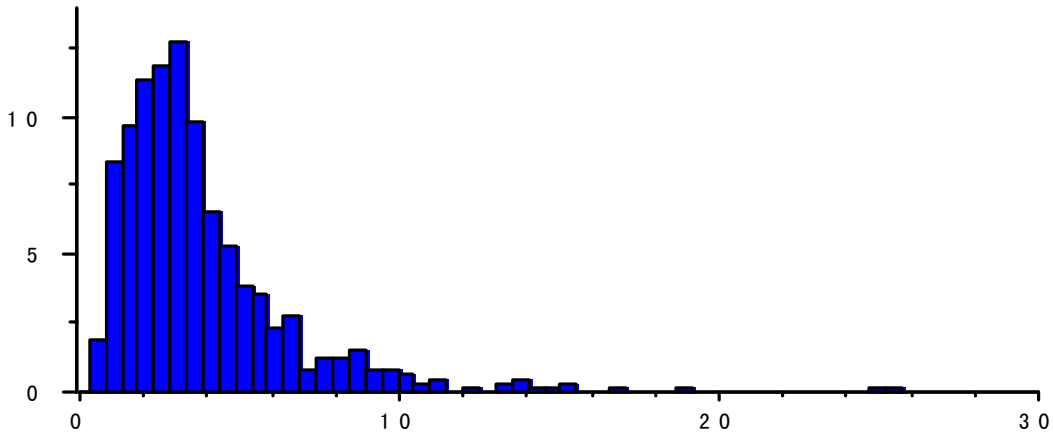



Figure 3. x= AP Pelvis, Skin dose(mGy), y=Percentile
(n=670, min=0.046mGy, max=18.364mGy)




Fugure 4. x= AP Lumbar spine, Skin dose(mGy), y=Percentile
(n=730, min=0.287mGy, max=25.732mGy)

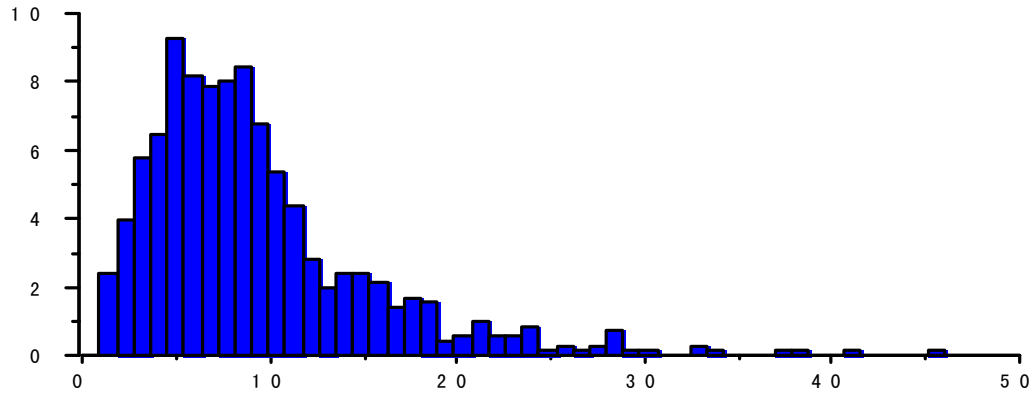



Figure 5. x=LAT Lumbar spine, Skin dose(mGy), y=Percentile
(n=710, min=0.940mGy, max=45.983mGy)

The Mann-Whitney U test was used to compare the film-screen (F/S) group and the computed

radiography (CR) group. For the PA chest radiography, null hypothesis was rejected at $p<0.0001$ level of significance (Fig. 6). This result indicated that the median of the F/S group was less than that of CR group. For the AP abdomen radiography, null hypothesis was rejected at $p=0.0031$ (Fig. 7).

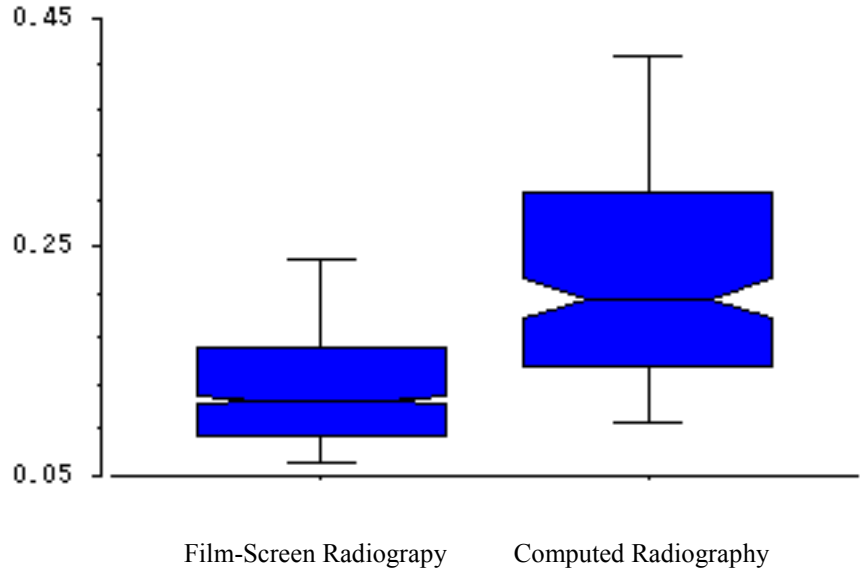



Figure 6. Skin doses (mGy) in PA chest radiography compared between film-screen and computed radiography ($p<0.0001$). The lower bars show the 10 percentile doses, the lower borders of the boxes show the 25 percentile doses, the waists of the boxes show the median doses, the upper borders of the boxes show the 75 percentile doses, and the upper bars show the 90 percentile doses.

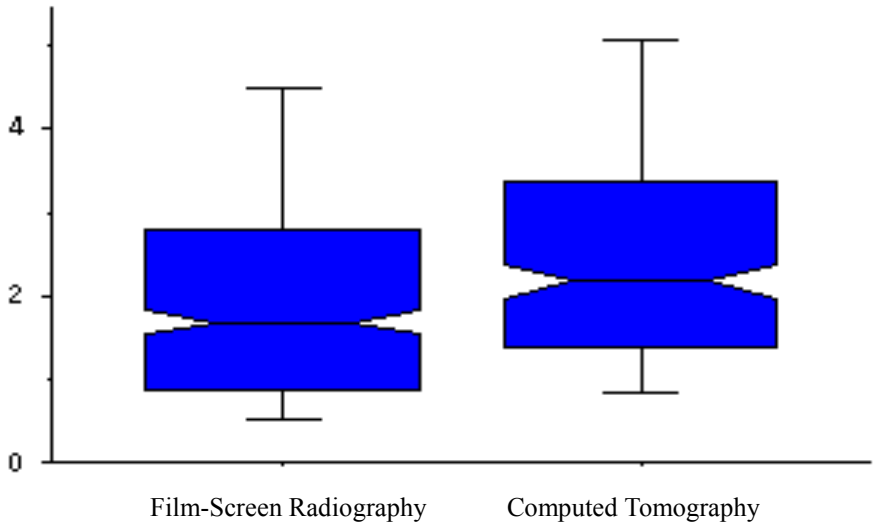



Figure 7. Skin doses (mGy) in AP abdomen radiography compared between film-screen and computed radiography ($p=0.0031$).

The Mann-Whitney U test was used to compare the groups where the automatic exposure control was used or not. The null hypotheses were rejected for PA chest radiography at $p=0.085$ (Fig. 8), AP abdomen radiography at $p<0.0001$ (Fig. 9), and LAT lumbar spine radiography at $p=0.0295$ (Fig. 10). In the three types of

radiography, the median dose in automatic exposure control group was less than that of manual control group.

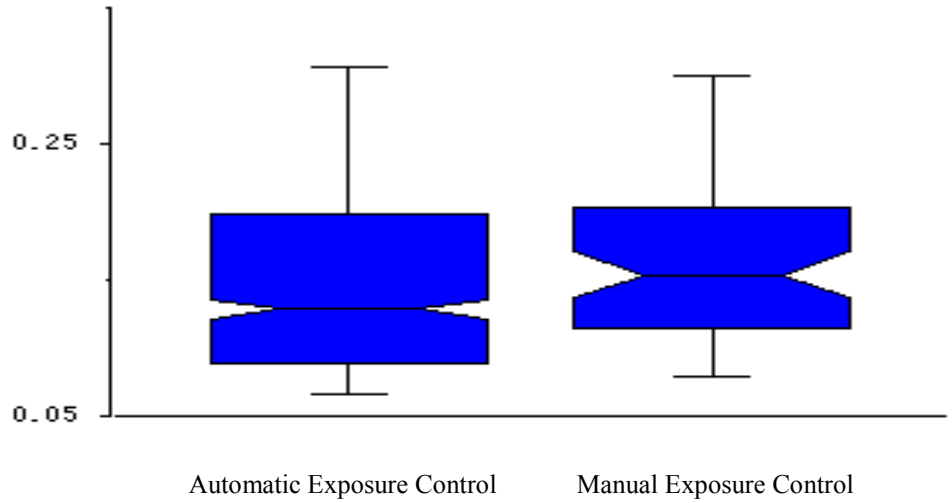



Figure 8. Skin doses (mGy) in PA chest radiography compared between automatic exposure control and manual exposure control (p=0.085).

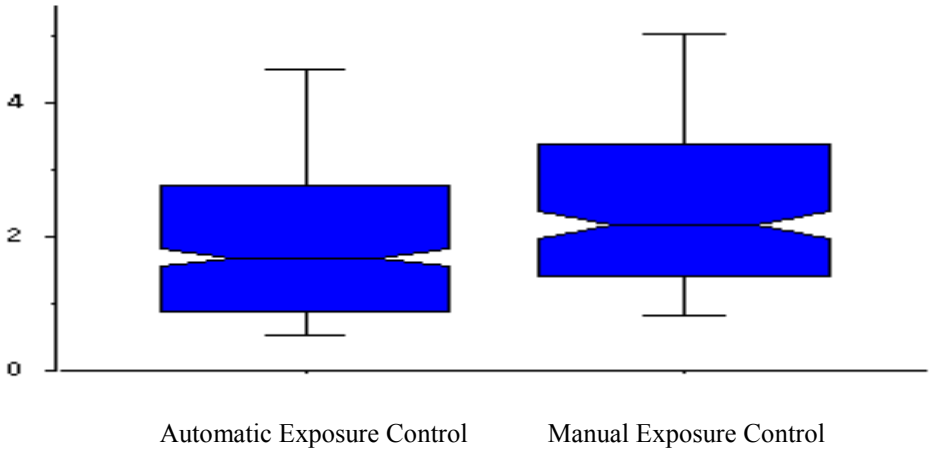



Figure 9. Skin doses (mGy) in AP abdomen radiography compared between automatic exposure control and manual exposure control (p<0.0001).

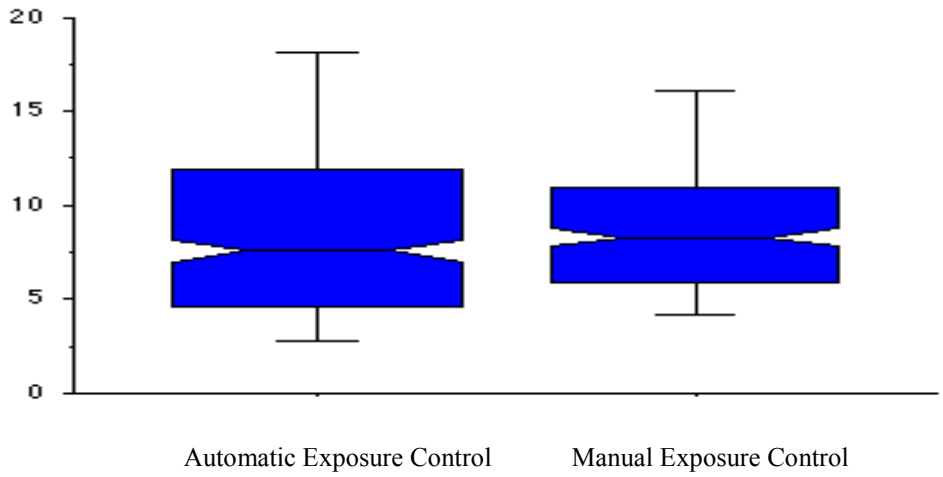



Figure 10. Skin doses (mGy) in LAT lumbar spine radiography compared between automatic exposure control and manual exposure control (p=0.0295).

The Spearman's rank correlation coefficients were calculated for body thickness vs. skin dose and grid rate vs. skin dose. The coefficients were 0.482 and –0.174, respectively, and no significant correlation was observed. Simple regression analysis between the technical factor; $V^2$ x mAsec / $FSD^2$ (tube voltage squared x tube current x exposure time / FSD squared), and the calculated dose showed a good correlation (corrected R^2, 0.883) (Fig. 11). Multiple regression analysis from the technical factor ($V^2$ x mAsec / $FSD^2$), patient's body thickness and the total x-ray filtration to the calculated dose showed a correlation with a corrected R^2 of 0.897 (Fig. 12). Little improvement was observed from the simple regression analysis to the multiple regression analysis, indicating that factors of the body thickness and the filtration had relatively small contribution to the regression, and that the technical factor has a major influence to the calculated dose.

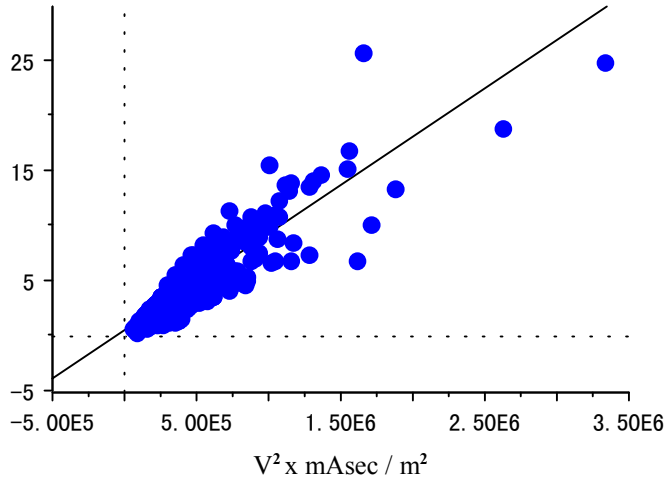



Figure 11. Simple regression analysis between technical factor (x axis, $V^2$ x mAsec / $FSD^2$) and calculated dose (y axis, mGy) (corrected R^2=0.883).

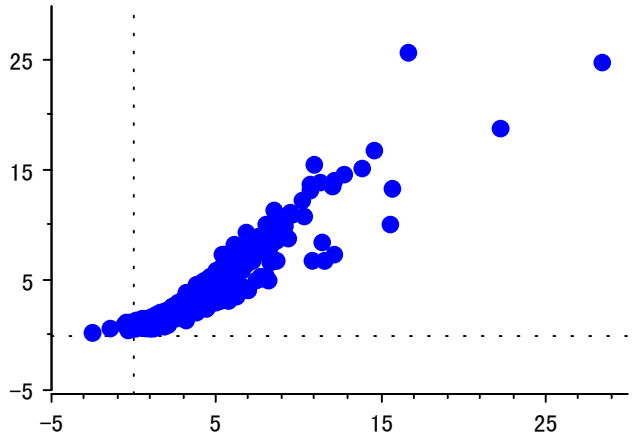



Figure 12. Multiple regression analysis from the technical factor ($V^2$ x mAsec / $FSD^2$), patient's body thickness and the total filtration to the calculated dose (corrected R^2=0.897). x axis: multiple regression value of the calculated dose, y axis: calculated dose.

## Direct Measurement

Data of 311 radiographs (55 to 65 radiographs for each type of examination) were obtained from 13 university hospitals and compared with the results of the calculation method. Table 2 shows the correlation coefficients between the skin doses obtained by TLD dosimetry and by NDD-M method in each hospital. The correlation coefficients ranged from 0.72 to 1.00, indicating that the calculated dose well correlated to the directly measured dose in each institution. However, when the total data from all hospitals were compared, the correlation coefficient for PA chest radiograph decreased to as low as 0.06. Figure 13 shows distribution of the calculated dose and the measured dose in 55 PA chest radiographs from 11 hospitals. The data from 3 hospitals were far lower or higher than the others. When the data from the remaining 8 hospitals were evaluated, good agreement was shown between the calculated dose and the measured dose (Fig. 14). In the other 4 types of radiography, TLD dosimetry gave good agreement with the calculation method (correlation coefficient, 0.62 to 0.88).

Table 2. Thecorrelation coefficients between the skin doses obtained by direct measurement and by the calculation method.

| Hospital | PA Chest | AP Abdomen | AP Pelvis | AP Lumbar spine | LAT Lumbar spine |
|---|---|---|---|---|---|
| A | 0.88 | 1.00 | 0.99 | 0.99 | 0.99 |
| B | 0.99 | 1.00 | 0.98 | 1.00 | 0.99 |
| C | 0.96 | 0.98 | 0.86 | 0.97 | 0.82 |
| D | 0.83 | 0.99 | 1.00 | 1.00 | 0.99 |
| E | 0.90 | 0.99 | - | 0.98 | 0.94 |
| F | 1.00 | 0.92 | 0.98 | 0.99 | 0.98 |
| G | 0.97 | 0.94 | 0.92 | 1.00 | 0.99 |
| H | - | 0.99 | 0.92 | 0.95 | 0.73 |
| I | 0.99 | 1.00 | 1.00 | 0.99 | 0.99 |
| J | - | 0.99 | - | 0.94 | 1.00 |
| K | 0.99 | 0.82 | 0.77 | 0.72 | 0.88 |
| L | 0.98 | 0.99 | 0.91 | 0.98 | 0.80 |
| M | 0.73 | 0.82 | 0.96 | 1.00 | 0.93 |
| Total | 0.06 | 0.62 | 0.85 | 0.88 | 0.84 |

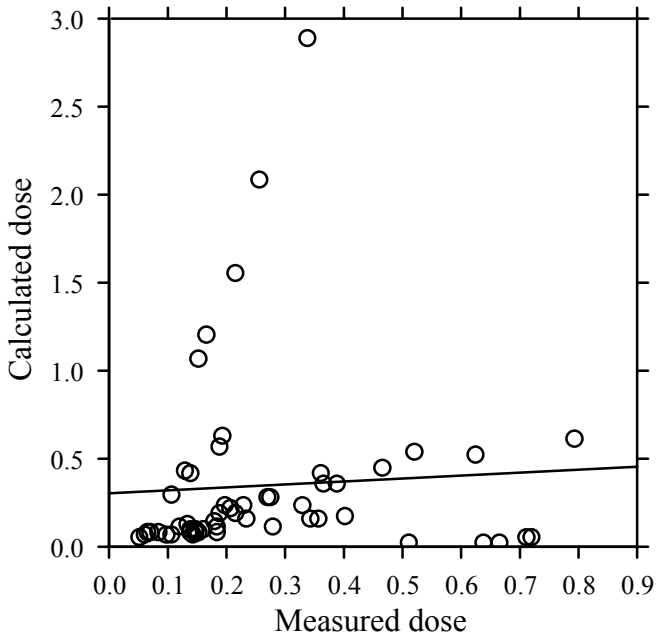



Figure 13. Correlation of skin doses (mGy) by direct measurement and calculation method in 55 PA chest radiographs at 11 hospitals. R^2= .003.

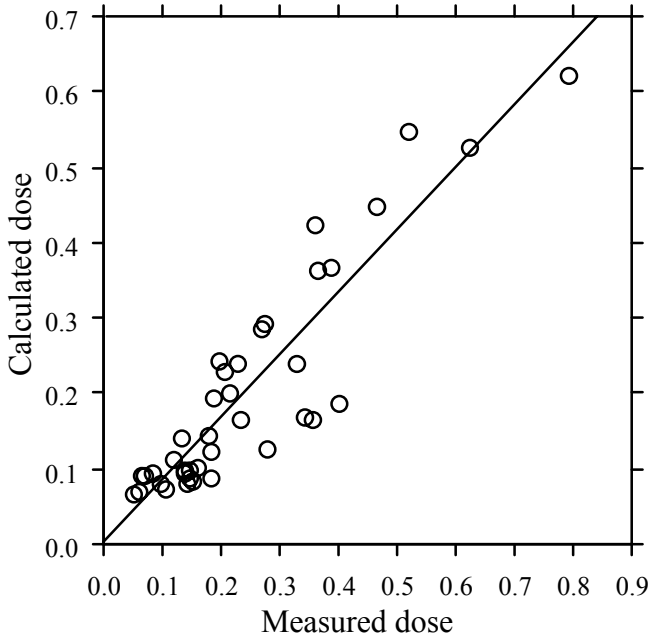



Figure 13. Correlation of skin doses (mGy) by direct measurement and calculation method in 40 PA chest radiographs at 8 hospitals. R^2= .829.

## DISCUSSION

The guidance levels of radiation exposure by radiographic examinations have been recommended as a safety standard under the condition that clinically satisfactory image quality would be guaranteed in the majority of medical institutions (1). The IAEA guidance levels are suited for typical European adults (2-4). For introducing the guidance levels to Japan, smaller body size of Japanese people and the recent technical developments including computed radiography and automated exposure control must be taken into consideration. In the present multicenter study using a calculation method, a wide distribution of the radiation dose was demonstrated in each type of radiography. From the statistical analyses, x-ray conditions including tube voltage and current was shown to be a major factor contributing the calculated skin dose. In PA-chest and AP-abdomen examinations, calculated skin doses were significantly larger with computed radiography than with conventional film-screen systems. Use of automated exposure control system was also shown to be a significant factor for increase of radiation dose in PA-chest, AP-abdomen and LAT lumbar spine examinations.

The results from direct dose measurement by TLDs performed in the selected institutions showed that the calculation method gave good agreement with the direct measurement in four types of examinations (AP abdomen, AP pelvis, AP and LAT lumbar spine). In PA-chest examination, mismatches were seen between the two methods in three of eleven institutions (27.3 %), although the doses by two methods showed a good correlation in each institution. This mismatch may be partly explained by the fact that Japan Industrial Standard (JIS) permits the error range of tube voltage (+/- 10%), tube current (mA, +/- 15%) and mA x exposure time (mAs, 20%). The sum of these error can greatly influence the x-ray output. Also, periodical check-up of these parameters is also mandatory for maintaining the accuracy of x-ray output. We believe that presently used calculation method is reliable under the condition that the quality control and maintenance of the x-ray equipment is appropriately managed.

The third quartile (75-percentile) value of the calculated doses by the routine radiographic examinations were fairly smaller than the IAEA guidance levels (28 to 47 %). However, further research may be needed to discuss the overall advantage, cost and appropriateness to recommend smaller guidance levels in Japan.

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