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RADIOLOGY PHYSICS
ORIGINAL ARTICLE

Dose audit for patients undergoing two common radiography examinations with digital radiology systems

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PURPOSE
We aimed to determine the radiation doses delivered to patients undergoing general examinations using computed or digital radiography systems in Turkey.

MATERIALS AND METHODS
Radiographs of 20 patients undergoing posteroanterior chest X-ray and of 20 patients undergoing anteroposterior kidney-ureter-bladder radiography were evaluated in five X-ray rooms at four local hospitals in the Ankara region. Currently, almost all radiology departments in Turkey have switched from conventional radiography systems to computed radiography or digital radiography systems. Patient dose was measured for both systems. The results were compared with published diagnostic reference levels (DRLs) from the European Union and International Atomic Energy Agency.

RESULTS
The average entrance surface doses (ESDs) for chest examinations exceeded established international DRLs at two of the X-ray rooms in a hospital with computed radiography. All of the other ESD measurements were approximately equal to or below the DRLs for both examinations in all of the remaining hospitals. Improper adjustment of the exposure parameters, uncalibrated automatic exposure control systems, and failure of the technologists to choose exposure parameters properly were problems we noticed during the study.

CONCLUSION
This study is an initial attempt at establishing local DRL values for digital radiography systems, and will provide a benchmark so that the authorities can establish reference dose levels for diagnostic radiology in Turkey.

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Standard radiology procedures in projection radiography (plain films or digital equipment) account for 48% of all diagnostic radiology examinations and contribute 41% to the collective dose (1). One of the main reasons for introducing the diagnostic reference level (DRL) concept was to investigate situations where patient doses are unusually high. Therefore, DRLs provide a valuable method for dose optimization (2). The as-low-as-reasonably-achievable principle should be considered in such dose-optimization processes. Surveys have shown variation by as much as two magnitudes in the doses to patients undergoing the same X-ray examinations (3). This wide variation in patient dose proves that there is room to optimize the radiography process. There is also considerable evidence that substantial reductions in these medical exposures are possible without detriment to patient care (4).

To reduce the radiation dose to the patient, guidelines must be followed for appropriate levels of exposure. The International Commission on Radiological Protection (ICRP) and European Commission have recommended the use of DRLs (3–5). It has been recommended that the 75th percentile or third quartile of the dose distribution in a population of standard-sized patients is an appropriate level for the DRL (5). According to the Commission of European Communities, the purpose of DRLs is to encourage radiology departments to investigate their patient radiation doses and make historical, national, or international comparisons (6). To our knowledge, there are no published Turkish data on patient doses in general radiography with digital X-ray systems. Torres et al. (7) made the following statement: the implementation of these new technologies requires an estimation of the doses that are actually being administered in clinical practice, in order to check that, in cases of both day-to-day practice and optimization protocols, doses are kept within reference values and as low as achievable in relation to the aimed image quality. This statement also holds true for Turkey.

In Turkey, many X-ray examinations are performed using new technologies such as computed radiography (CR) and direct digital radiography (DR), although no DRLs for conventional radiography practices published by national authorities have investigated this new equipment, which has the potential to deliver lower patient doses than previous X-ray devices. Council Directive 97/43 of the European Atomic Energy Community defines DRL and expects member states to promote the establishment of DRLs for radiodiagnostic examinations. Therefore, national DRLs should be defined by national authorities, and European levels have already been established.

The objectives of this study were to perform a radiation dose audit, to compare the results of the patient dose survey with international DRLs

for both examinations, to present the study results to radiologists in Turkey in order to draw attention to the patient doses using digital radiography systems, and to observe improper practices in the clinics studied.

Materials and methods

The radiation dose measurements were performed on a sample of 20 average-size patients undergoing posteroanterior (PA) chest X-rays and another 20 average-size patients undergoing anteroposterior (AP) kidney-ureter-bladder (KUB) radiographs. The measurements were done onfrequently performed examinations due to their high impact on the collective dose.

Measurements were made in five X-ray rooms at four local hospitals in the Ankara region; in one hospital, doses were measured in two X-ray rooms. Patients were observed for each examination with each system, resulting in dose data for 200 X-ray examinations: 100 from PA chest and 100 from AP KUB examinations. Three of the systems were CR systems, and the other two were DR systems (Table 1). The survey was conducted after local ethics comitte approval.

One X-ray room had a Sireskop system (Siemens Healthcare, Erlangen, Germany), two rooms had Bucky Diagnost systems (Philips Healthcare, Eindhoven, The Netherlands) with FCR Profect CS Plus CR systems (Fujifilm Medical, Tokyo, Japan), one room had a Digital Diagnost system (Philips Healthcare), and one room had a RadPRO Elite system (Canon Inc., Lake Success, New York, USA). Although all of the systems have been subjected to established quality control protocols since the date of installation, all of the X-ray tubes and generators were tested before measuring patient doses according to Institute of Physicists and Engineers in Medicine procedures (8). Each patient record was stored in a digital data file to facilitate the calculation of entrance surface doses (ESDs). A form, containing information on the patient (gender, age, weight) and technical exposure parameters used (applied tube voltage, tube current, and exposure time, and X-ray field size in the film plane) was filled out for each examination.

Doses were measured without changing the exposure parameters that the local technologists use and prefer in their daily practice. The preferences for exposure parameters and positioning techniques were also observed in every department.

Two different tools were used to measure the doses. First, the X-ray tube outputs were measured at a distance of one meters the X-ray tube voltages were increased from 50 to 150 kVp in 10 kVp steps using a Model 90X6-6 calibrated 6 cc ion chamber, connected to a Radiation monitor controller model 9010 (Radcal Corporation, Monrovia, California, USA). All ESD values were calculated retrospectively from the tube output measurements (9).

In addition, a kerma area product (KAP) meter (M4DK, PTW, Freiburg, Germany) KAP ion chamber was used to calculate the tube outputs to correlate the previous measurement technique and entrance surface air kerma (ESAK) estimations.

The KAP meter had two ion chambers: one transparent area ion chamber for the KAP and one at the center for air kerma measurements. The central ion chamber of the KAP meter was used for crosschecking of the ESAK calculations obtained from the tube output measurements (10). The KAP values were not included in the patient dose database. The ion chambers of the KAP meter were calibrated *in situ* against an ion chamber (Radcal Corporation, Monrovia, California, USA) before the measurements began using the procedure proposed by the manufacturer and other researchers (11, 12).

The ESD was calculated from the tube output measurements using the following formula:

$$ESD = Y(d) \times P \times \left(\frac{d}{a-b}\right)^2 \times BSF \times \left(\mu_{en}/\rho\right)_{air}^{tiss}$$

where $Y(d)$ is the X-ray tube output measured at distance d from the tube focus; a is the focus-to-bucky-surface distance; b is the patient thickness; BSF is the backscatter factor; $(\mu_{en}/\rho)_{tiss}$ and $(\mu_{en}/\rho)_{air}$ are the mass energy absorption coefficients for tissue and air, respectively; P is the mAs value that was used for the patient exposure; and T is the mass energy absorption coefficient ratio and equaled 1.06 for the kVp range used in this study (13). $Y(d)$ was measured for all possible kV settings and was also divided by the mAs value with which the measurement was made (9). To obtain the ESD from the air kerma, the BSF used for adult radiography was 1.35, as suggested in the European Guidelines (4). An experienced radiologist reviewed all of the radiographs using the image criteria in the European Guidelines.

ESD values that were measured with two methods were compared via linear correlation analysis, and an interclass correlation analysis was also carried out.

Results

The mean patient weight was 74.1±8.62 kg (range, 55–115 kg), and the mean height was 1.75±0.05 m (range, 1.60–1.94 m). Most of the pa-

Table 1. Specifications of the radiography equipments included in this survey

X-ray room	Model	Manufacturer	Equipment no.	Technology	Support equipment	AEC/tec.
1	Sirescop	Siemens Healthcare	1	Computed radiography	Profect CS Plus, Fujifilm Medical	No/low kVp
2, 3	Bucky Diagnost	Philips Healthcare	2	Computed radiography	Profect CS Plus, Fujifilm Medical	No/low kVp
4	Digital Diagnost	Philips Healthcare	1	Digital radiography	-	Yes/high kVp
5	RadPro Elite	Canon Inc.	1	Digital radiography	-	Yes/high kVp

AEC, automatic exposure control; tec., exposure technique.

tients were young males, between 18 and 23 years old, and were close in height and weight to the standard human body size defined by ICRP (3). The mean patient body mass index was 24.44±3.3 kg/m^2. ESAKs were calculated from tube output measurements and from the KAP meter central point ion chamber measurements in order to compare and cross-check all ESAK calculations. The correlation coefficient was R^2=0.90 for the PA chest and R^2=0.94 for the AP KUB ESAK calculations, as seen from Figs. 1 and 2, respectively. The high correlation coefficients proved that the measured ESAK values were reliable in a methodological sense. In addition, an interclass correlation coefficient analysis was carried out for both dose datasets, giving correlation coefficients of 0.92 for the PA chest and 0.87 for the AP KUB dose measurements. These high interclass correlation coefficients indicate that either of the dose datasets obtained from the different dose measurement methods can be used. Table 2 gives the ESAK values with their range for both examinations.

The maximum patient dose measured for chest examinations was 45-fold greater than the minimum patient dose, while for the AP KUB examinations this difference was 24-fold (Table 2). These big differences are due to the very low dose results obtained for one of the X-ray rooms. The room equipped with Philips Digital Diagnost (room 4) had a direct current X-ray generator and all exposures were much shorter than for the mean exposure times for the other four room. In addition, this department used 150 kVp for all chest examinations. Due to the very short exposure times and high kVp used, all of the measured ESAK values from this room were very low. The ESAK measurements for the other four rooms were close to each other in both types of examination. Table 3 gives the exposure parameters for both examinations.

The differences in the kVp values used in the PA chest examinations were larger than the differences in the AP KUB examinations (Table 2). This was due to the technologists' preference for low kVp settings with the CR equipped X-ray systems, since CR plates have lower spectral sensitivity, while the technologists working with DR preferred high kVp settings for chest examinations. The parameter settings of the CR and DR equipment used for abdominal X-rays were closer to each other compared to the chest images. The European Guidelines suggest using a high kVp for PA chest examinations, e.g., 125kV values (i.e., 120 and 150 kVp) were used in the two X-ray rooms (rooms 4 and 5) equipped with DR systems (4).

All radiographs from both the CR and DR systems were adequate and had good image quality for diagnosis according to image criteria recommended by the European Guidelines (4). Using a high kV with DR systems results in shorter exposure times, which lowers the mAs values and patient dose.

In the clinics with CR systems, the technologists prefer manual settings with a low kV and high mAs. It has been observed that positioning the X-ray tube close to the patient also causes a higher patient dose.

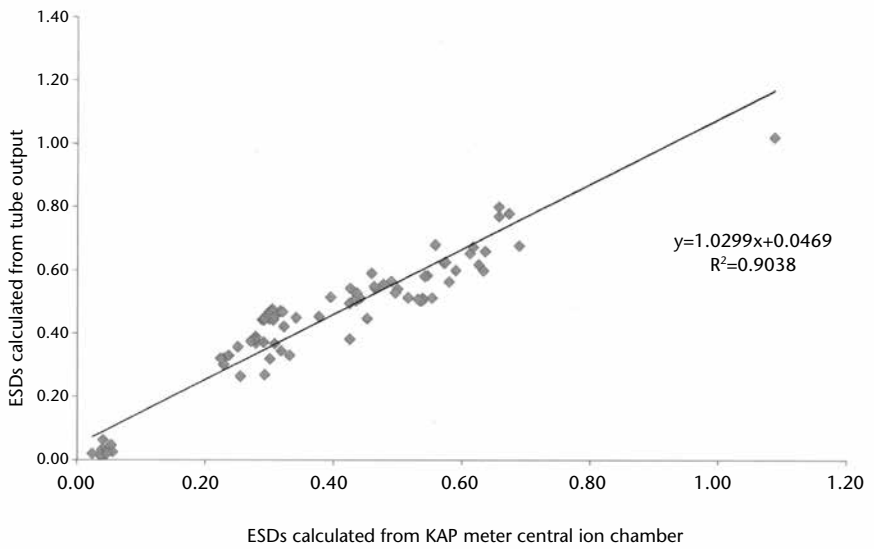

Figure 1. The entrance surface doses (ESDs) calculated from tube output vs. the value calculated from reading for the central ion chamber of the kerma area product (KAP) meter for the postero anterior chest examinations. The correlation coefficient (R^2) between the datasets was 0.9038.

Table 2. ESD values in comparison with European Union diagnostic reference levels for posteroanterior chest and anteroposterior kidney-ureter-bladder radiography examinations

	Entrance surface dose value (mGy)			
Examination	Diagnostic reference level	Mean±SD	Minimum	Maximum
Posteroanterior chest	0.3	0.346±0.2	0.024	1.087
Anteroposterior kidney-ureter-bladder	10	1.948±1.1	0.264	6.288

SD, standard deviation.

Discussion

The differences in the kV values for the AP KUB examinations were less significant due to the low kVp used in both CR and DR systems. The AP KUB examination is a low kV application, although sometimes this technique produces results with high mAs numbers in large patients. However, the maximum calculated ESD was still lower than in the DRL for this examination in the European Guidelines (Table 1). All of the radiographs obtained with both the CR and DR systems had good image quality and were adequate for diagnosis according to the European Guidelines criteria (4).

The chest examination is probably the most predominant use of a low-

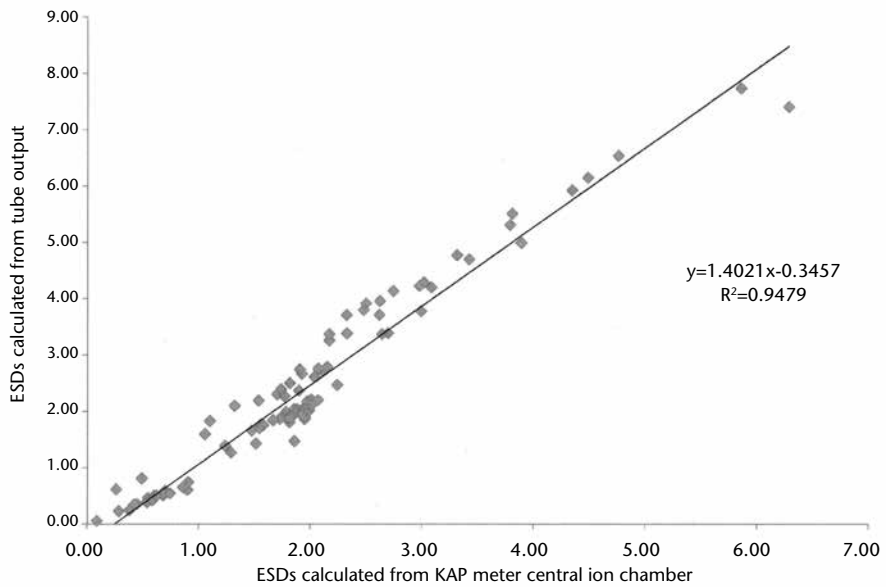

Figure 2. The entrance surface doses (ESD) calculated from tube output vs. the value calculated from reading for the central ion chamber of the kerma area product (KAP) meter for the anteroposterior kidney-ureter-bladder radiography examinations. The correlation coefficient (R^2) between the data sets was 0.9479.

Table 3. Exposure factors and focal-skin distance values for posteroanterior chest and anteroposterior kidney-ureter-bladder radiography examinations

	kVp		mAs		Focal-skin distance (cm)	
Examination	Mean	Range	Mean	Range	Mean	Range
Posteroanterior chest	98.14	64.5–150	12.06	0.25–31.7	148.41	135.1–162.5
Anteroposterior kidney-ureter-bladder	74.32	64.5–87.5	26.45	0.98–66.1	89.14	76.6–103.4

kV, kilovolt; mAs, milliamper per second.

kVp technique with typical tube potentials of 64.5–87 kVp. This contrasts the European recommendation to use a high-kVp technique (i.e.,125 kVp). As mentioned, only the two rooms equipped with DR systems used a high kVp. The CR system users preferred low-kVp techniques for chest examinations based on service engineer recommendations and the recommended target S values in the manufacturer's manuals (i.e., 150–300). The European Guidelines recommend using a high kVp with a 400-speed film-screen combinations using automatic exposure control (AEC). This is not the case with CR systems used clinically. In this study group, the CR system technologists did not use AEC, but set the exposure parameters manually.

To implement the high-kVp chest technique in CR-equipped X-ray rooms, the AEC systems must be recalibrated for CR plates. In Turkey, most AEC systems are calibrated for 400-speed film-screen usage; when compared with film-screen combinations, CR plates refer to 200-speed film-screens. We are conducting an ongoing study to recalibrate AEC systems for CR plate usage in order to implement high-kVp usage for PA chest examinations. The kVp settings for the AP KUB examinations were in the range of kVp settings (75–90 kV) recommended in the European Guidelines. All measured ESDs were below the DRL of 10 milligrays (mGy) in the European Guidelines.

A further survey of patient doses after establishing local DRLs will be a good tool for patient dose management and an example of the effective adjustment of patient doses. Even if patient age is not the main concern in determining DRLs, it is easier to collect data on patients of average weight and size by measuring young patients (5). Since most of the measured ESD values for the PA chest examinations exceeded the European Union DRL of 0.3 mGy and the International Atomic Energy Agency DRL of 0.4 mGy, further dose measurements and recalibration of the AEC systems are needed to optimize them and establish a national DRL for this examination. In our ongoing study to recalibrate AEC ion chambers for CR plates, the preliminary results show that the goal can be achieved in some systems. All of the measured ESD values were below the European Union DRL of 10 mGy for KUB AP examinations, and there does not seem to be a need to optimize this examination; however, extending the measured data will also help to achieve an accurate national DRL for this examination. A practical procedure for patient dose monitoring with respect to the DRLs is used only rarely in many hospitals in Turkey. The main reason for the values being two times higher than the European reference level for chest radiography (PA) is likely the predominant use of a low-kVp technique with typical tube potentials of 60–80 kV and antiscatter grid use in CR installations. The possible reasons for the large dose discrepancies seen are the use of non-optimized digital systems, different viewing preferences of clinicians, and different postprocessing parameters. Moreover, older and newer plates were used during the same time period for every room and both examination type.

This study had some limitations. First, measuring different technologies, such as CR and DR, increases the differences between dose values, which introduces difficulty in comparing measured patient doses. Second, a group of five X-ray machines is smaller than needed to make a strong decision regarding DRLs, even for local settings. Third, instead of using an ion chamber for ESAK measurements, using thermoluminesence dosimeters on the skin of the patients might produce more reliable data, since it measures the energy delivered to the body directly. Despite these drawbacks, we have obtained the preliminary results to present to the local radiology community.

In conclusion, as patient dose values for general radiography can increase during the transition from conventional screen-film radiography to CR, dose management programs for digital techniques, specific training of radiographers, and frequent patient dose audits can improve practice, while maintaining or reducing patient doses (14–16). In this study, the patient doses were generally acceptable, except for chest X-rays at two CR installations, compared to the published dose levels. Problematic areas that need further investigation and improvement included improper adjustment of the exposure parameters, uncalibrated AEC systems, and hesitation of the technologists to use AEC systems correctly, especially for CR systems.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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