Application of dose-area product compared with three other dosimetric quantities used to estimate patient effective dose in diagnostic radiology

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Background: Application of dose-area product (DAP) quantity has been increased in the clinical practice. DAP is relatively easy to measure, and has been shown to correlate well with the total energy to the effective dose imparted to the patient correlated. ***Materials and Methods:*** Measurements of DAP were carried out with 421 adult patients who underwent conventional radiological examinations. Then, some useful dosimetric quantities such as exposure area product (EAP), air kerma and entrance surface dose (ESD) were estimated. Furthermore, effective doses were computed by the measurement of DAP and corresponding conversion factors. ***Results:*** The effective dose values derived from various methods are in good agreement. The mean effective dose estimated from DAP measurements were 0.13, 0.42, 0.05, 0.59, 0.54 and 0.03 mSv/projection for chest, abdomen, cervical spine, lumbar spine, pelvis and skull examinations, respectively. ***Conclusion:*** Indirect effective dose determination using the NRPB dosimetric data and the measured value of DAP or ESD allows for reliable estimates of effective dose. The ODS-60 software was used in this study as to it's flexibility to manipulate the technical parameters of an examination and patient's parameters. ***Iran. J. Radiat. Res., 2006; 4 (1): 21-27***

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INTRODUCTION

Use of X-ray facilities and equipments has increased rapidly in medical practices. Diagnostic radiology has an enormous share of public dose from man-made sources. In fact diagnostic radiology is, so far, the largest source of man-made radiation. For example, diagnostic radiology and nuclear medicine procedures are the cause of about 88% of collective effective dose from man-made sources in the US (1, 2).

To assess the stochastic risk from nonhomogeneous radiation, ICRP has recommended determination of effective dose. The effective dose has been introduced to express a radiation dose related detriment in situations where the dose to the patient body is not uniform. Effective dose is formally defined as the sum of the weighted equivalent doses to organs ($E = \Sigma H_T W_T$). The normalization process that requires ΣW_T=1 causes inconsistencies in radiation detriment estimates for very nonhomogeneous irradiations (1-6).

The most preferred and complete approach for risk estimation is an accurate knowledge of all pertinent organ doses and the appropriate risk coefficient for the relevant age, gender and organ. In practice, however, this idealistic approach is difficult to achieve, and a single index is desirable to express relative radiation detriment, when possible. Thus, while the ICRP recommendation weighting factors may yield incorrect values of absolute and relative radiation detriment, the concept of "Effective Dose" remains operationally useful for certain instances in diagnostic radiology.

The use of Monte Carlo techniques and the previous studies in this field have led to the conclusion that an indirect reliable estimate of E can be obtained by measuring the entrance surface dose (ESD), dose-area product (DAP), or the energy imparted and multiplied these by appropriate conversion coefficients which have been determined for specific X-ray projections, or even for complete examination procedure (7-9).

The main aims of this study were to determine some useful dosimetric quantities such as air kerma, exposure-area product

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(EAP) and entrance surface dose (ESD) based on DAP measurements and effective dose using various methods.

MATERIALS AND METHODS

The study group included 210 male and 211 female patients. They were selected randomly from a much larger group of patients who had referred to the radiographic department of Ghaem and Emdady hospitals over a six months period. The geometrics and radiographic parameters were recorded for six common radiographic examinations (10 views) which are as follows: chest (AP and PA), cervical spine (AP and Lat), lumbar spine (AP and Lat), pelvis (AP), abdomen (AP), and head (PA and Lat). All the examinations (excluding head) were preformed on Siemens units. Head examinations were preformed on a Shimadzu (model YSF-100) unit. For all units, total filtration was 3.5 mm aluminum corresponding to a 3.38 mm aluminum at 80 kV. For each unit the quality control was preformed with a multi-o-meter dosemeter.

Dose-area product (DAP)

DAP-meters measure the product of radiation dose to air and the area of the X-ray field. DAP is expressed in $Gy.cm^2$ or $mGy.cm^2$. An ionization chamber larger than the area of the X-ray beam is placed just under the X-ray collimators. The DAP ionization chamber must intercept the entire X-ray field for an accurate reading; this quantity is proportional to EAP. The reading from a DAP-meter can be changed by either altering the X-ray technique factors (kVp, mAs or time), or varying the area of the field or both.

Various dosimetry quantities are used for patient dosimetry. Patient dose may be determined in different ways; however, regardless of the method used, DAP or alternatively EAP, or air kerma must be available to the researcher. The dosimetric quantities can be computed by employing the radiographic parameters and the measured radiation output of the X-ray machine, or by using surface dose or dose-area product measurements of actual patient examinations. Relation between DAP and ESD is given by the following equation:

$$DAP = D_{FCD}(air) \times A_{FCD} = D_{FSD}(air) \times A_{FSD} = (ESD/BSF) \times A_{FSD} = (ESD/BSF) \times A_{FFD} \times (FSD/FFD)^2 \quad (1)$$

Where $D_{FCD}(air)$ is the absorbed dose to air at the DAP-meter position (collimator) and is the irradiated area at the DAP position. The FSD and FFD are the focus-skin distance and focus-film distance, respectively.

In order to estimate the effective dose, we needed to determine DAP value ($mGy.cm^2$), kV, total filtration and common diagnostic X-ray projections. For each exposure, DAP was measured by a DAP-meter (Gammex-RMI, model 840A). This instrument is capable of measuring output of two X-ray tubes at the same time, with a suitable energy range of 50-150 kVp and absorption of less than 0.5 mm aluminum. The instrument transmits information to a connected computer every 5 ms.

Estimated conversion coefficients to relate measured values of DAP to effective dose (E) are presented in NRPB report 262-1994[5]. We calculated effective dose by using certain coefficients presented in this report.

The effective doses were determined from the indirect measurements made separately for adult males and females by the following equation:

$$E(mSv) = DAP\ (mGy.cm^2) \times CC_{dap}(mSv/mGy.cm^2) \quad (2)$$

For each X-ray projection CC_{dap} is a function of kilo voltage and total filtration.

Entrance surface dose (ESD)

ESD is defined as the absorbed dose to air at the center of the beam, including backscattered radiation. ESD can easily be measured by TLD or SDM (skin dose monitor), but an estimate of the ESD can be obtained by muliplying the absorbed dose to air by the appropriate backscatter factors. In the absence of an appropriate dosemeter to measure DAP or ESD, a reliable estimate of the ESD, and consequently of the effective dose, could be obtained by recording the exposure data for a particular X-ray projection and estimated absorbed dose to air, in combination with backscatter factors available in literature. In the current study, the ESD values for each exposure were determined by the following equation:

$$ESD_{(mGy)} = output \times (kV/85.2)^2 \times (100/FSD)^2 \times mAS \times BSF \quad (3)$$

Where output is the output of the X-ray tube at 85.2 kV at a distance of 100 cm normalized by mAs (mGy/mAs), kV is the tube potential, mAs is the product of the tube current and exposure time, FSD is the focus skin distance and BSF is the backscatter factor. The output (mGy/mAs) for each unit was measured in the 50-150 kVp range (10 kV steps) by a Multi-O-Meter dosemeter. To convert exposure (mR) to output the following equation has been used:

$$output_{(mGy/mAs)} = \left[X(mR)/0.0087\right]/mAs \quad (4)$$

The variation of output (mGy/mAs) at 100 cm from the focal spot with kVp is given in figure 1. Furthermore, the BSF depends on the X-ray spectrum and beam size which is typically of the order of 1.3 (the practical range of BSF is 1.1-1.5). In this study, the BSF was taken equal to 1.3 for all projections, since the BSF variation for the field sizes and kVps used for these examinations is not significant. Effective doses were determined by using equation 5:

$$E(mSv) = ESD(mGy) \times CC_{ESD}(mSv/mGy) \quad (5)$$

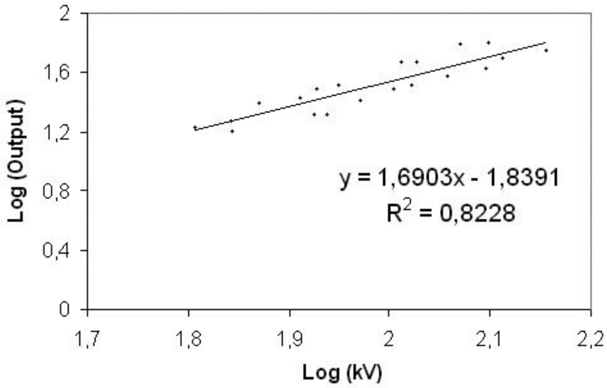

Figure 1. Output (µGy/mAs) variation with tube potential for the siemens units.

Where CC_{ESD} is the conversion coefficient to relate ESD values to effective doses, which were estimated by the NRPB-262 [1, 5, 6, 10].

Energy imparted

Energy imparted is a measure of the total ionizing radiation energy deposited in the patient during a radiological examination and may be used to quantify the patient dose in diagnostic radiology. The value of the energy imparted, ε, is a stochastic quantity due to the statistical fluctuations in the number and type of interaction processes occurring in the volume. The energy imparted in the patient undergoing diagnostic radiology may be estimated from the incident entrance exposure area product (EAP). For each exposure the DAP reading by DAP-meter can be converted to the EAP by the following equation:

$$EAP(mRcm^2) = 0.0087 \times DAP(mGycm^2) \quad (6)$$

The energy imparted was calculated in the following way:

$$\varepsilon = w(z) \times EAP \quad (7)$$

Where w(z) is the energy imparted to a water phantom of thickness z cm for an X-ray beam with a cross-sectional area of 1 cm^2 normalized to unit exposure (free-in-air) at the phantom surface. The value of w(z) may be obtained from the following equation.

$$w(z) = \alpha \times HVL + \beta \quad (8)$$

Where α and β are parameters of the fit and they depend on the tube potential and patient thickness. Values of α and β were obtained by Huda *et al.* [11]. HVL value is a function of tube voltage and total filtration HVL was derived from another study [12].

The values of energy imparted were converted to the corresponding patient effective dose, E, by equation 9:

$$E_{mSv} = \varepsilon \times (E/\varepsilon)_i \times 70.9/M \quad (9)$$

Where $(E/\varepsilon)_i$ is the effective dose per unit energy imparted for the ith examination and M (kg) is the patient mass. The values of $(E/\varepsilon)_i$, α and β parameters that correspond to the values of tube voltage (kV) and phantom thickness (z) applicable in this study are presented in table 1 (12-15).

Table 1. Range values of $\left(\frac{E}{\varepsilon}\right)_i$ $\left(mSvj^{-1}\right)$ and mean α and β parameters used in this study.

Examination	kVp	$\left(\frac{E}{\varepsilon}\right)_i$	Z	HVL	α	β	w(z)
Chest PA	122	15.25-16.07	20	5.39	1.562	5.454	138.73
Chest AP	83	22.01-22.66	20	3.48	2.007	3.206	101.90
Abdomen AP	80	20.83-21.61	23	3.39	2.100	3.020	101.29
Cervical S.AP	74	23.34-23.90	18	3.14	2.015	2.630	89.57
Cervical S.Lat	79	4.26-4.60	22	3.35	2.097	2.980	100.05
Lumbar S.AP	91	23.06-23.91	23	3.86	2.002	3.652	113.70
Lumbar S.Lat	100	9.97-10.53	25	4.36	1.930	4.310	125.20
Pelvis AP	82	24.97-25.31	23	3.47	2.080	3.150	103.67
Head PA	74	4.66-4.77	22	3.14	2.150	2.690	94.41
Head Lat	68	4.84-5.00	18	2.90	2.060	2.260	82.34

ODS-60 computer program

The package ODS-60 developed by Rados Technology in Turku, Finland is capable to compute patient specific organ dose and effective dose from X-ray examinations. ODS-60 is a combination of two modules, a size and sex-adjustable phantom model, and a set of algorithms to calculate the absorbed dose to an arbitrary point in the phantom. The absorbed doses to the organs in the ODS-60 program are calculated using Monte Carlo simulated dose distributions for a semi-infinitive, water slab of 30 cm thick. For each projection, the irradiation geometry, voltage (kV), focus-to-skin distance (FSD), total filtration, field area, air kerma and patient's weight, height, and genders are given as input data. In this software, the patient weight and height could vary from 40-110 kg and 40-200 cm, respectively (16).

The dosimetric input quantity is the air kerma, K_{air} (mGy), at the distance specified by the focus-to-skin distance, FSD. Entrance surface dose, ESD (mGy), is given by:

$$ESD = f_{D,K} \times BSF \times K_{air} \qquad (10)$$

Where $f_{D,K}$ is the conversion factor between air kerma and absorbed dose-to-air. In the present work $f_{D,K}$ is taken equal to one. If equation 10 is combined with equation (1), the result is as follows:

$$K_{air} = DAP/A_{FSD} \qquad (11)$$

A_{FSD}, is the X-ray field area at FSD.

RESULTS

Table 2 summarizes the number of patients for each projection (examination or view), as well as the applied geometric factors. Male and female patients were grouped separately. The corresponding values adopted by NRPB are also tabulated in table 2. Totally, 421 patients (210 males and 211 females) were examined. Table 3 summarizes the key dosimetric parameters for ten types of radiographic examinations included in this study. These parameters are: measured kVp by multi-O-meter, mAs values as read from the selector of the X-ray machine, measured DAP values by DAP-meter, calculated ESD value and ε.

The values of effective dose as computed in this study and also those obtained by employing other methods are given in figure 2. The average effective dose to patients of

Table 2. Average geometric data used in the present work vs. the corresponding data adopted in NRPB simulations.

Examination	Projection	Number of patients		FSD(cm) a)			A_{FFD} b)		
				This work		NRPB	This work		NRPB
		Female	Male	Female	male		Female	Male	
Chest	AP	25	25	115	123	160	37*39	37*39	35*44
	PA	25	25	130	130	160	37*40	37*39	35*44
Abdomen	AP	25	25	82	83	75	38*44	38*42	35*47
Cervical S.	AP	26	26	78	78	75	21*24	22*24	18*24
	LAT	20	17	78	80	75	23*24	23*24	17*23
Lumbar S.	AP	12	12	74	82	75	26*46	27*45	30*43
	LAT	13	13	68	69	60	24*51	24*50	20*45
Pelvis	AP	25	25	80	85	75	38*40	38*39	42*41
Head	PA	20	22	83	85	75	26*30	26*30	24*30
	LAT	20	20	83	83	80	30*25	30*24	28*23

a) FSD is the focus to skin distance. b) A_{FFD} is the X-ray field area at the FFD.

Table 3. Average exposure values used to calculate effective dose.

Projection	mAs	DAP	ESD (mGy)	K_a (mGy)	ε (mj)	CC_{DAP} a)	CC_{ESD} b)
Chest AP	31	629	0.74	0.57	5.4	.204-.262	.171-.215
Chest PA	16	578	0.67	0.51	6.5	.195-.215	.159-.173
Abdomen	58	1881	2.56	1.83	16.5	.192-.260	.125-.162
Cerv S. AP	35	341	1.48	0.92	2.7	.227-.247	.043-.047
Cerv S. Lat	36	351	1.68	0.99	3.0	.033-.043	.006-.008
Lum S. AP	72	2699	4.85	4.54	18.3	.249-.327	.120-.153
Lum S. Lat	84	2340	5.68	3.61	26	.157-.182	.036-.042
Pelvis AP	61	2076	2.93	2.23	19	.209-.295	.148-.190
Head PA	26	1176	----	1.67	9.0	.025-.031	----
Head Lat	18	778	----	1.15	5.0	.027-.031	----

a) Range of CC_{DAP} in this study. b) Range of CC_{ESD} in this study.

both sexes was derived from equations (2) and (5), produced by different diagnostic examinations were compared. The differences are as follow: 4.5% for chest in AP and 4.6% in PA projections, 3.5% for abdomen, 4% for pelvis, 16% for cervical spine in AP and 7% in LAT projections, 14.5% for lumbar spine in AP and 14% in LAT projections, and 4% for pelvis examinations. (average difference 8.7%). Similarly, the average effective dose acquired from equation (2) and ODS-60 software were compared, and the differences are as following: 17.5% for chest in AP and 19% in PA projections, 17% for abdomen, 7.5% for cervical spine in AP and 22% in LAT projections, 25.5% for lumbar spine in AP and 7.5% in LAT projections, 20% for pelvis, 14% for head in PA and 28% in LAT projections (average difference 17.8%). Hence, the average effective doses derived from the application of equations (2) and (9) were compared and the

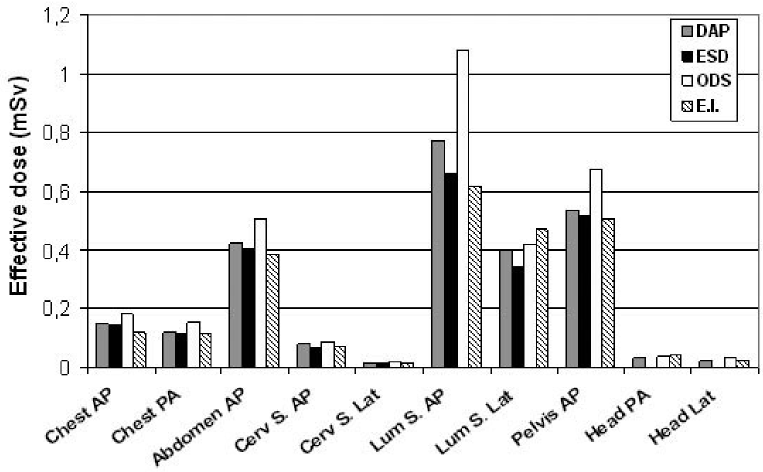

Figure 2. Effective dose (mSv) estimated by employment of DAP, ESD, energy imparted and ODS package to female, male and averaged value for both sexes.

differences are as following: 18.5% for chest in AP and 5.5% in PA projections, 8.5% for abdomen, 12% for cervical spine in AP and 10.5% in LAT projections, 20.5% for lumbar spine in AP and 15.5% in LAT projections, 6% for pelvis, 23.5% for head in PA and 7.5% in LAT projections (average difference 12.8%).

DISCUSSION

Results show that the effective dose values derived from equation (2) have been in a very good agreement with the corresponding figures acquired from equation (5). Similarly, the effective doses calculated by using equation (9) have not been significantly different. (Head examination in PA view is excepted). Furthermore, effective doses obtained from equation (2) and those computed by ODS-60 are usually in good agreement, excluding lumbar spine examination in AP view. Average effective dose for male and female patients based on application of DAP and ESD measurements, have not been significantly different (p>0.05). Lumbar spine (AP view) and pelvis examinations are exceptional. Average effective dose for male and female patients based on application of energy imparted and ODS-60 calculations have not been significantly different (p>0.05). Abdomen and lumbar spine and pelvis examinations are exceptional. Effective dose from chest examination in the PA projection has been higher than the corresponding value for the PA projection by 18%; because almost all radiosensitive organs, such as breast and gonads, are anteriorly located in the anterior part of human body.

Other researchers such as: Nikolaos *et al.* (15), Kaul *et al.* (8) and Aroua *et al.* (12) have also attempted to assess effective dose of patients undertaking X-ray examinations of different kinds. Their results, together with ICRP-60 and NCRP-89 recommendations, are compared with the values of effective dose acquired for male and female patients arising from six conventional X-ray examinations in this work. As it is evident from table 4, this study is providing a set of more comprehensive information in

Table 4. Mean effective doses estimated in this study and other studies together with ICRP-60 and NCRP-89 recommendations

Examination	This Study		Nikolaos *et al.* (1997)	Kaul *et al.* (1997)	Aroua *et al.* (2002)	ICRP-60	NCRP-89
	Male	Female					
Abdomen-AP	0.381	0.46	0.180	1.2	1.34	-	-
Chest-PA	0.123	0.121	0.037	0.3	2.92	0.033	0.08
Skull-PA	0.034	0.034	0.0078	0.03	-	-	0.22
Pelvis	0.472	0.607	-	1.05	-	1.22	0.44
Cervical Spine	0.082	0.079	-	0.2	-	-	0.2
Lumbar Spine	0.566	0.981	-	2	3.44	0.59	1.27

comparison with other studies.

In this study, we obtained some useful dosimetric quantities such as entrance surface dose, air kerma, exposure area product, and energy imparted by DAP measurement. DAP measurements combined with NRPB data have enabled us to estimate the effective dose reliably. DAP meter is a convenient and useful tool to assess the effective dose in the radiological departments, as it does not cause penumbra on the film. In other words, it does not interfere with radiological procedures at any stage; and therefore, it does not affect the quality of the image. Although NRPB has derived CC_{DAP} and CC_{ESD} from a single phantom, and these coefficients are considered equal for both sexes nevertheless our calculated effective dose for male and female patients were not equal. The differences were nearly in the same range as those produced by ODS-60 method, which was derived from separate male and female phantoms. The ODS-60 software was applied in this study, due to it's flexibility to manipulate the technical parameters of an examination and patient's parameters such as weight, height, and sex. The software can also be utilized when the geometrical parameters are changing. This will provide researchers to cover a wide range of diagnostic examinations. Its computing speed is faster than the similar software.

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