https://doi.org/10.1186/s43055-024-01337-5

Egyptian Journal of Radiology and Nuclear Medicine

RESEARCH

Open Access

Comparison of directly and indirectly estimated entrance skin dose (ESD) for diagnostic radiation qualities (RQR, RQA and RQT) using water phantom and shadowfree diagnostic chamber (SFD)

Umar Hussain Haider[1*], Babar Hussain[2], Wajeeha Shaheen[2] and Shakeel Ur Rehman[1]

Abstract

Background The aim of this study was to find the entrance skin dose (ESD) for diagnostic radiation qualities RQRs, RQAs and RQTs given in IAEA technical report series No. 457 using direct and indirect methods of measurement. Measurements were done for 5 × 5, 10 × 10, 15 × 15, 20 × 20 and 25 × 25 cm^2 field sizes and 70, 80, 90 and 100 cm source to surface distance (SSD) using shadow-free diagnostic (SFD) chamber and water phantom having dimension 30 × 30 × 30 cm^3. ESD direct measurements were done by placing SFD chamber on the surface of water phantom, while in the case of indirect measurements, air kerma values were obtained.

Results ESD values for different selected radiation qualities RQR2, RQR5, RQR8, RQR10, RQA2, RQA5, RQA8, RQA10, RQT8, RQT9 and RQT10 were found to be in the range of 0.0045–5.11 mGy per examination.

Conclusions Results obtained were found to be comparable with ESD values published in the literature. The obtained results in this research would help in establishing the national diagnostic reference levels (DRLs) which would help in the optimization of diagnostic imaging procedures. It would also help the radiographers to optimize field sizes and SSDs in order to reduce dose to the patients thereby ensuring good radiological practices, and this would reduce the stochastic risk to the patients caused by the ionizing radiations.

Keywords Entrance skin dose, Diagnostic radiology, Direct and indirect methods, Water phantom, SFD ion chamber

Background

The entrance skin dose (ESD) or surface dose is defined as the absorbed dose (mGy) when radiation reaches the patient. ESD is dependent on beam energy, beam angle, field size, source to surface distance, phantom size and beam modifier devices [1]. For skin dose assessment, International Commission on Radiation Units and Measurements (ICRU) and International Commission on Radiological Protection (ICRP) recommend the skin dose at the depth of 0.07 mm which corresponds to the interface between epidermis and dermis layer of the skin [2]. Diagnostic radiology practices like general radiography and computed tomography (CT) is increasing day by day in all over the world because of their undoubted clinical benefits [3]. ESD is received by the patients during diagnostic radiology practices. Use of ionizing radiation in diagnostic radiology can be

*Correspondence:
Umar Hussain Haider
umarstg88@gmail.com
[1] Pakistan Institute of Engineering and Applied Sciences (PIEAS), Islamabad, Pakistan
[2] Pakistan Institute of Nuclear Science and Technology (PINSTECH), Islamabad, Pakistan

linked with the development of cancer, that is, stochastic effects in the patients, but these doses are well below the doses that can cause deterministic effects, so basic radiation protection concept is ALARA which states that all exposures must be as low as reasonably achievable [4, 5]. ESD is a dose descriptor to quantify diagnostic reference levels (DRLs). Therefore, knowledge of surface dose or ESD is an important consideration in diagnostic radiology [6].

As studied in the literature, there is no single in vivo or in vitro representation for ESD estimations for diagnostic qualities (RQRs, RQAs and RQTs) given in TRS-457. ESD can be measured directly using ion chambers and thermoluminescent dosimeters placed on the patient's surface. It can also be indirectly measured in air using established formulism. IAEA BSS (1996) [7] sets ESD DRLs in the range of (0.4–30 mGy) for different X-ray examinations [8]. European Commission (EC) 1996 [9] describes ESD as a quantity to be monitored per radiograph. The ESD recommendations for an adult of average size in plain radiography set by the Australian radiation protection and nuclear safety agency range from a minimum of 0.2 mGy (Chest PA) to a maximum of 26 mGy (Lumber spine spot) [10]. Patients exposure to radiation has been increased all over the world due to diagnostic X-ray examinations which may cause stochastic effects to the patients. It is the main responsibility of the radiologists to establish local DRLs and accurately assess this unavoidable dose to the skin to make radiology practices as safe as possible [6, 7, 9].

Radiation quality in radiation (RQR) shows the radiation beam incident on the patient in fluoroscopy, general radiography and dental radiography. RQR5 is known as reference radiation quality used in general radiography as unattenuated beam. Radiation quality based on aluminum added filtration (RQA) and radiation quality based on copper added filtration (RQT) are established by using added filtration of aluminum and copper, respectively. RQA5 is used as reference radiation quality used in general radiography as attenuated beam. Similarly, RQT9 is the reference radiation quality for CT [11].

The aim of this study was to investigate the ESD per examination for different field sizes and SSDs for diagnostic radiation qualities RQRs, RQAs and RQTs using direct and indirect methods of measurement. These radiation qualities are given in TRS 457.

Methods

All measurements were performed at secondary standard dosimetry laboratory (SSDL), Pakistan. A diagnostic X-ray machine (tube model E7240FX and collimator model 5,129,405) was used to produce collimated beam of X-ray photons. This X-ray machine produces X-rays in the range (40–150) kVp. A PTW SFD chamber (model TM 34060 and Sr No. 00098) in conjunction with PTW-Freiberg electrometer (model TM 4060) was used for the measurements. For X-ray qualities RQAs and RQTs, IBA-made (IBA Dosimetry Inc. Germany) and locally fabricated added filtration of aluminum and copper (area = 8×8 cm^2, thickness varying from 0.022 to 13.1 mm) was placed at the center of square fields. Direct ESD measurements were made with ion chamber placed on the front surface of IAEA standard PMMA water phantom of dimensions $30 \times 30 \times 30$ cm^3. This phantom dimension provides full scattering for the field size being used. Indirect measurements were taken in air and ESD was calculated by multiplying air kerma value with backscatter factor and water to air mass energy absorption coefficient ratio. The chamber was positioned at the center of square fields. Irradiation time was 1 s and current was set to 10 mA. Calibrated barometer (all model MK2) and a digital thermometer (model HTC-2) were used for pressure and temperature measurements.

The SFD Ion chamber used in this work has traceability to IAEA primary laboratory at Vienna with mean air kerma calibration coefficient of 0.36 mGy/nC. ESD was determined using the following relations:

$$\text{ESD (Direct method)} = X(\text{nC}) \times K_{P,T} \times Nk\ (\text{mGy/nC}) \quad (1)$$

$$\text{ESD (In-direct method)} = \text{Kair}\ (\text{mGy}) \times \text{Bair} \times \left(\frac{\mu_{\text{en}}}{\rho}\right)_{w,\,\text{air}} \quad (2)$$

$$\begin{aligned} &\text{ESD (In-direct Method)} \\ &= X(\text{nC}) \times Nk(\text{mGy/nC}) \\ &\times K_{P,T} \times \text{Bair} \times \left(\frac{\mu_{\text{en}}}{\rho}\right)_{w,\text{air}} [12] \end{aligned} \quad (3)$$

where K_{air} is air kerma, X=uncorrected charge value, $K_{P,T}$ = pressure temperature correction factor, N_k is air kerma calibration coefficient, B_{air} is backscatter factor and $\left(\frac{\mu_{\text{en}}}{\rho}\right)_{w,\text{air}}$ is air to water mass energy absorption coefficient. $K_{P,T}, B_{\text{air}}$ and $\left(\frac{\mu_{\text{en}}}{\rho}\right)_{w,\text{air}}$ are unitless quantities. Values of B_{air} and $\left(\frac{\mu_{\text{en}}}{\rho}\right)_{w,\text{air}}$ for the X-ray qualities were taken from published data [13, 14].

Results

Measurements of ESD for RQRs

Measurements were taken for the charge values given in Table 1, and ESD (direct and indirect) was calculated using Eqs. 1 and 2. ESD measurements for RQRs for different field sizes and SSDs are shown in Table 1. Exposure time

Table 1 ESD measurement of RQRs

SSD (cm)	RQRs	Field size (cm^2)	Potential (kV)	Mean charge (direct) (nC)	Entrance skin dose (ESD) (direct) (mGy)	Mean charge (indirect) (nC)	Entrance skin dose (ESD) (indirect) (mGy)
100	RQR2	5×5	40	0.06419	0.02528	0.06175	0.02794
		10×10		0.27225	0.10724	0.25	0.11584
		15×15		0.303	0.11935	0.26675	0.12408
		20×20		0.31025	0.1222	0.269	0.12559
		25×25		0.314	0.12368	0.27	0.12618
90		5×5		0.0875	0.03447	0.086	0.03897
		10×10		0.33825	0.13323	0.308	0.14293
		15×15		0.379	0.14928	0.32775	0.15269
		20×20		0.38675	0.15233	0.329	0.15383
		25×25		0.39	0.15361	0.32925	0.1541
80		5×5		0.145	0.05071	0.13475	0.06091
		10×10		0.429	0.16898	0.4165	0.19277
		15×15		0.47575	0.18739	0.4155	0.19482
		20×20		0.4835	0.19044	0.4175	0.19647
		25×25		0.488	0.19222	0.4185	0.19714
70		5×5		0.201	0.07932	0.18675	0.08441
		10×10		0.59275	0.2339	0.533	0.24669
		15×15		0.627	0.24742	0.551	0.25602
		20×20		0.638	0.25176	0.553	0.25788
		25×25		0.643	0.25373	0.554	0.2586
100	RQR5	5×5	70	0.25875	0.10122	0.259	0.12138
		10×10		1.19875	0.46892	1.0475	0.51712
		15×15		1.36225	0.53288	1.12125	0.55852
		20×20		1.41175	0.55224	1.1285	0.56712
		25×25		1.4365	0.56192	1.1315	0.56992
90		5×5		0.37825	0.14784	0.31525	0.14796
		10×10		1.51825	0.5934	1.286	0.63581
		15×15		1.695	0.66249	1.371	0.68395
		20×20		1.75375	0.68545	1.3775	0.69329
		25×25		1.78225	0.69659	1.378	0.69511
80		5×5		0.54475	0.21291	0.57025	0.26694
		10×10		1.935	0.75629	1.74525	0.86057
		15×15		2.15475	0.84218	1.761	0.8842
		20×20		2.2275	0.87061	1.771	0.8971
		25×25		2.261	0.88371	1.77475	0.90104
70		5×5		0.878	0.34305	0.78425	0.36712
		10×10		2.60175	1.01655	2.225	1.09715
		15×15		2.83	1.10573	2.304	1.14636
		20×20		2.9105	1.13718	2.31075	1.15992
		25×25		2.95825	1.15584	2.314	1.16419
100	RQR8	5×5	100	0.54525	0.21627	0.50725	0.24817
		10×10		2.42325	0.96117	2.1065	1.10946
		15×15		2.81975	1.11844	2.26075	1.21397
		20×20		2.94875	1.16961	2.2735	1.24474
		25×25		3.01725	1.19678	2.28	1.25537
90		5×5		0.8715	0.31261	0.691	0.33858
		10×10		2.736	1.20144	2.586	1.36404
		15×15		3.42975	1.38798	2.76075	1.48468
		20×20		3.60625	1.44766	2.772	1.51995

Table 1 (continued)

SSD (cm)	RQRs	Field size (cm^2)	Potential (kV)	Mean charge (direct) (nC)	Entrance skin dose (ESD) (direct) (mGy)	Mean charge (indirect) (nC)	Entrance skin dose (ESD) (indirect) (mGy)
		25×25		3.68925	1.47848	2.77525	1.53035
80		5×5		1.20225	0.47406	1.11575	0.54525
		10×10		3.99225	1.57419	3.5085	1.84572
		15×15		4.46925	1.76228	3.54225	1.91729
		20×20		4.64625	1.83207	3.55975	1.96453
		25×25		4.73075	1.86539	3.5675	1.97995
70		5×5		1.78675	0.70492	1.53025	0.74782
		10×10		5.27375	2.08065	4.46625	2.34961
		15×15		5.82675	2.29882	4.625	2.48068
		20×20		6.04525	2.38503	4.639	2.53696
		25×25		6.1505	2.42655	4.64575	2.55504
100	RQR10	5×5	150	0.98625	0.39146	0.99425	0.50653
		10×10		5.0405	2.00068	4.305	2.44099
		15×15		5.83825	2.31733	4.6325	2.72413
		20×20		6.15475	2.45597	4.66	2.83904
		25×25		6.33075	2.5262	4.67175	2.88449
90		5×5		1.6645	0.66266	1.308	0.66737
		10×10		6.3685	2.53539	5.2875	3.00257
		15×15		7.26575	2.8926	5.65525	3.33054
		20×20		7.5835	3.0191	5.6735	3.46169
		25×25		7.7685	3.09275	5.6825	3.51383
80		5×5		2.22025	0.88274	2.18125	1.10996
		10×10		8.221	3.26856	7.18725	4.07052
		15×15		9.16525	3.64398	7.25475	4.30019
		20×20		9.53975	3.79288	7.288	4.47556
		25×25		9.78025	3.8885	7.30075	4.54371
70		5×5		3.5035	1.39197	2.97975	1.51632
		10×10		10.76	4.27503	9.13175	5.1719
		15×15		12.0075	4.77067	9.459	5.55598
		20×20		12.4725	4.95542	9.484	5.77141
		25×25		12.875	5.11534	9.5005	5.85923

and tube current were 1 s and 10 mA, respectively. Figures 1 and 2 show variation of directly and indirectly ESD with field sizes and SSDs for radiation qualities RQR5 and RQR10, respectively.

Similar graphs were observed for RQR2 and RQR8. These graphs show increase in ESD with field size which is due to backscatter factor (BSF). There is sharp increase in ESD value from field size 5×5 cm^2 to 10×10 cm^2 because there is a large increase in BSF value in this range. For other square field sizes 15×15 cm^2, 20×20 cm^2 and 25×25 cm^2, variation in ESD value is little because BSF variation is very little between these successive field sizes [13].

Measurements of ESD for RQAs

For RQA measurements, added filtration of aluminum was used. Exposure time and tube current were 1 s and 10 mA, respectively. ESD measurements for RQAs for different field sizes and SSDs are shown in Table 2. Exposure time and tube current were 1 s and 10 mA, respectively. Figures 3 and 4 show variation of ESD with field

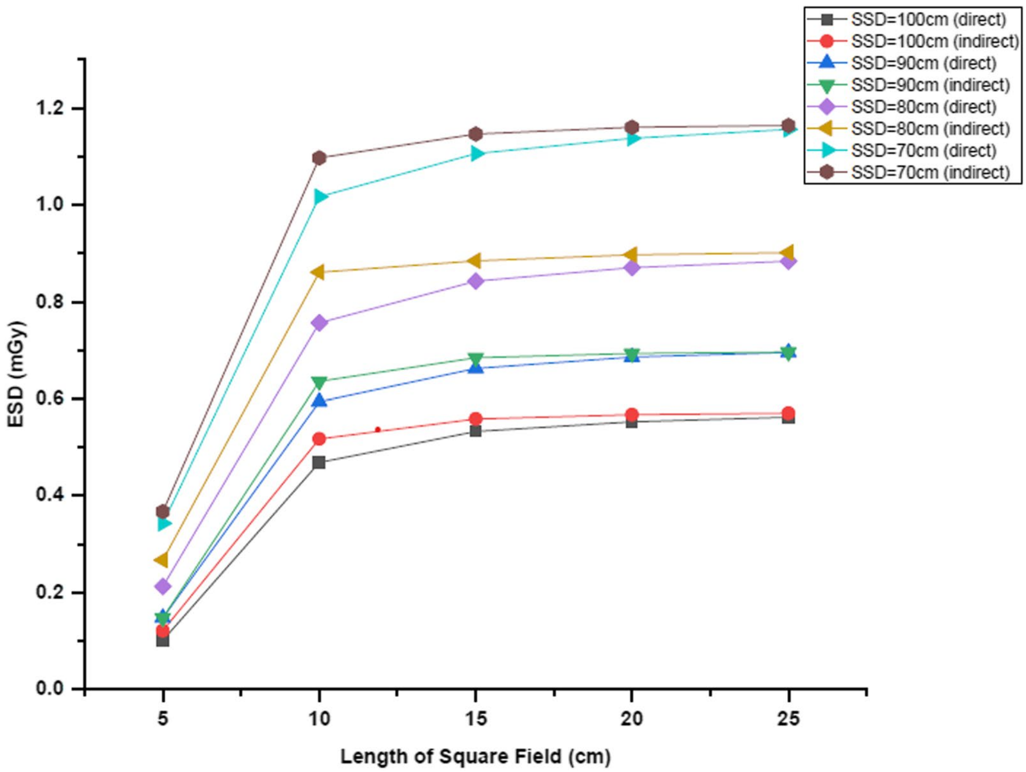

Fig. 1 Variation of ESD with field size for different SSDs using direct and indirect method (RQR5)

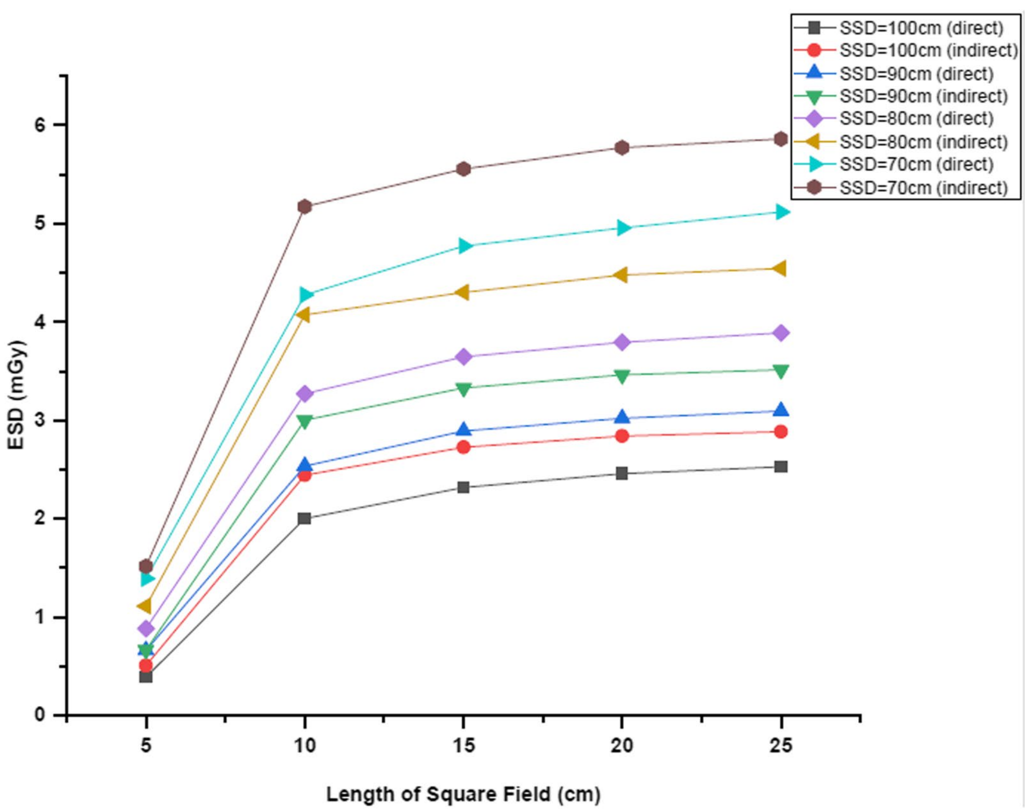

Fig. 2 Variation of ESD with field size for different SSDs using direct and indirect method (RQR10)

Table 2 ESD measurements for RQAs

SSD (cm)	RQA	Added filtration (mmAl)	Field size (cm^2)	Potential (kV)	Mean charge (direct) (nC)	Entrance skin dose (ESD) (direct) (mGy)	Mean charge (indirect) (nC)	Entrance skin dose (ESD) (indirect) (mGy)
100	RQA2	4	5×5	40	0.01655	0.00653	0.01410	0.00655
			10×10		0.06011	0.02372	0.05209	0.02522
			15×15		0.06725	0.02654	0.05676	0.02762
			20×20		0.06937	0.02738	0.05752	0.02812
			25×25		0.07082	0.02795	0.05828	0.02861
90			5×5		0.0235	0.00927	0.02108	0.00977
			10×10		0.07537	0.02975	0.06643	0.03207
			15×15		0.08358	0.03298	0.07063	0.03427
			20×20		0.08612	0.03399	0.07168	0.03495
			25×25		0.08791	0.0347	0.07274	0.0356
80			5×5		0.02917	0.01151	0.02775	0.01288
			10×10		0.09717	0.03834	0.085	0.04112
			15×15		0.10658	0.04205	0.08859	0.04307
			20×20		0.10992	0.04338	0.09015	0.04403
			25×25		0.11195	0.04418	0.09151	0.04487
70			5×5		0.04786	0.01887	0.04102	0.01901
			10×10		0.12865	0.05071	0.11207	0.05411
			15×15		0.14067	0.05545	0.11733	0.05693
			20×20		0.14433	0.05689	0.11993	0.05847
			25×25		0.14802	0.05835	0.12245	0.05993
100	RQA5	20.995	5×5	70	0.01128	0.00449	0.00986	0.00515
			10×10		0.04609	0.01835	0.03653	0.02128
			15×15		0.0555	0.02209	0.04022	0.0244
			20×20		0.06041	0.02405	0.04201	0.02642
			25×25		0.06361	0.02532	0.04331	0.02762
90			5×5		0.01626	0.00647	0.01427	0.00746
			10×10		0.05946	0.02367	0.04596	0.02679
			15×15		0.07011	0.02791	0.05042	0.03058
			20×20		0.07618	0.03033	0.05229	0.0329
			25×25		0.08006	0.03187	0.05431	0.03465
80			5×5		0.02484	0.00989	0.01901	0.00994
			10×10		0.07796	0.03104	0.05993	0.03492
			15×15		0.09114	0.03629	0.06439	0.03906
			20×20		0.09812	0.03907	0.06728	0.04233
			25×25		0.10243	0.04078	0.06902	0.04403
70			5×5		0.03245	0.01293	0.0265	0.01385
			10×10		0.10053	0.04004	0.08153	0.0475
			15×15		0.11675	0.0465	0.08836	0.05359
			20×20		0.12637	0.05033	0.0923	0.05807
			25×25		0.1314	0.05234	0.09401	0.05996
100	RQA8	34.002	5×5		0.02201	0.00887	0.01678	0.00893
			10×10		0.08837	0.03563	0.06998	0.04217
			15×15		0.10585	0.04267	0.07668	0.04882
			20×20		0.11658	0.047	0.08016	0.05363
			25×25		0.1236	0.04983	0.0846	0.05734
90			5×5		0.0297	0.01196	0.02277	0.01211
			10×10		0.11018	0.04438	0.08853	0.05328
			15×15		0.13348	0.05376	0.09674	0.0615

Table 2 (continued)

SSD (cm)	RQA	Added filtration (mmAl)	Field size (cm^2)	Potential (kV)	Mean charge (direct) (nC)	Entrance skin dose (ESD) (direct) (mGy)	Mean charge (indirect) (nC)	Entrance skin dose (ESD) (indirect) (mGy)
			20×20		0.14685	0.05915	0.10187	0.06806
			25×25		0.15555	0.06266	0.10615	0.07242
80			5×5		0.03585	0.01445	0.03079	0.01637
			10×10		0.13978	0.05635	0.11433	0.0688
			15×15		0.17047	0.06872	0.12565	0.07987
			20×20		0.18907	0.07622	0.1328	0.08872
			25×25		0.20075	0.08093	0.13835	0.09439
70			5×5		0.05484	0.02205	0.04857	0.02583
			10×10		0.1897	0.07627	0.15543	0.09353
			15×15		0.23125	0.09297	0.1706	0.10845
			20×20		0.256	0.10292	0.18083	0.12081
			25×25		0.26525	0.10664	0.18607	0.12695
100	RQA10	44.996	5×5	150	0.03897	0.01564	0.03504	0.01816
			10×10		0.1873	0.07517	0.1635	0.09497
			15×15		0.233	0.09351	0.181	0.11112
			20×20		0.255	0.10234	0.19	0.12274
			25×25		0.273	0.10957	0.198	0.13159
90			5×5		0.05685	0.02271	0.04829	0.02503
			10×10		0.242	0.09666	0.204	0.1185
			15×15		0.29675	0.11853	0.22675	0.1392
			20×20		0.323	0.12902	0.23875	0.15424
			25×25		0.349	0.1394	0.24975	0.16598
80			5×5		0.0791	0.0316	0.07072	0.03665
			10×10		0.3175	0.12683	0.268	0.15567
			15×15		0.381	0.1522	0.294	0.18049
			20×20		0.42175	0.16848	0.312	0.20156
			25×25		0.451	0.18016	0.329	0.21865
70			5×5		0.1164	0.04655	0.09571	0.049602
			10×10		0.432	0.17275	0.356	0.20679
			15×15		0.51525	0.20604	0.399	0.24495
			20×20		0.56875	0.22744	0.428	0.2765
			25×25		0.609	0.24353	0.448	0.29774

size and SSD for radiation qualities RQA2 and RQA10, respectively. These radiation qualities have application in measurements behind the patients. RQA5 (70 kV and 21 mm Al added filtration) is chosen as a reference radiation quality for attenuated beams for general radiography applications [11]. Explanation of the graphs of RQAs (Figs. 3, 4) is the same as described for RQRs. Further, we see that ESD values for RQAs are lower than RQRs because BSF values for all field sizes increase with incident beam energy and reach a maximum value between 50 and 70 keV; for higher energies (> 70keV), it decreases [13].

Measurements of ESD for RQTs

For RQTs, added filtration of copper (Cu) was used for measurements. Exposure time and tube current were 1 s and 10 mA, respectively.

Table 3 shows ESD measurements for RQTs for different field sizes and SSDs. Figure 5 shows variation of ESD with field sizes and SSDs for radiation qualities RQT9. RQT series represents unattenuated beam used in computed tomography. RQT9 (120 kV and 0.25 mm Cu added filtration) is chosen as a reference radiation quality for CT [11].

ESD values for RQTs are lower than RQRs because added filtration (Cu) absorbs the soft X-rays which would otherwise contribute to ESD. Deviation between direct

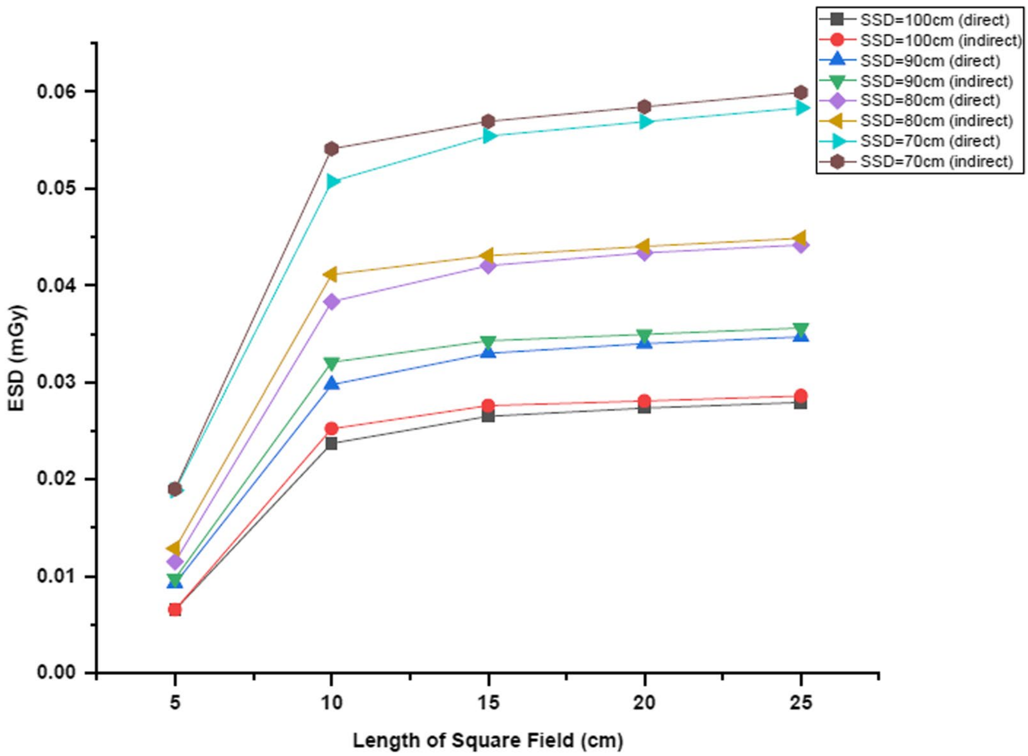

Fig. 3 Variation of ESD with field size for different SSDs using direct and indirect method (RQA2)

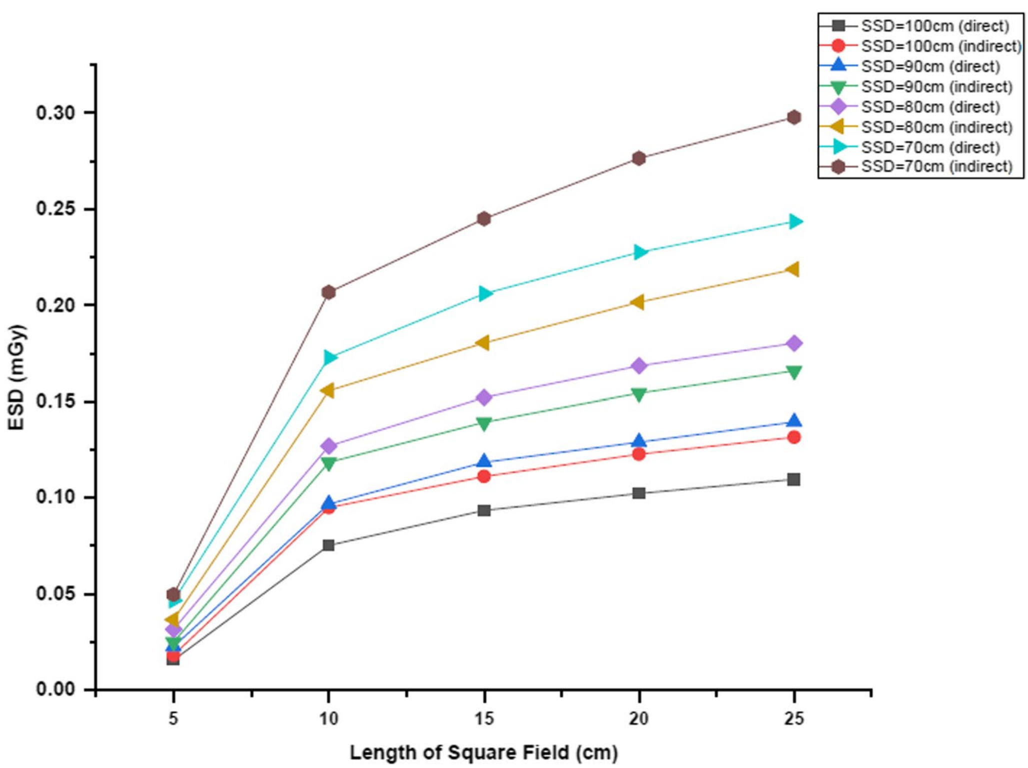

Fig. 4 Variation of ESD with field size for different SSDs using direct and indirect method (RQA10)

Table 3 ESD measurements for RQTs

SSD (cm)	RQT	Added filtration (mmCu)	Field size (cm^2)	Potential (kV)	Mean charge (direct) (nC)	Entrance skin dose (ESD) (direct) (mGy)	Mean charge (indirect) (nC)	Entrance skin dose (ESD) (indirect) (mGy)
100	RQT8	0.2	5×5	100	0.269	0.10497	0.223	0.11979
			10×10		1.0635	0.41499	0.855	0.51421
			15×15		1.303	0.50844	0.917	0.5747
			20×20		1.38	0.53849	0.93325	0.6085
			25×25		1.42375	0.55556	0.94325	0.62275
90			5×5		0.36425	0.14213	0.302	0.16073
			10×10		1.362	0.53146	1.067	0.63578
			15×15		1.60525	0.62638	1.137	0.70599
			20×20		1.698	0.66257	1.15475	0.74596
			25×25		1.748	0.68208	1.1665	0.76303
80			5×5		0.504	0.19921	0.419	0.21741
			10×10		1.76625	0.69814	1.447	0.84056
			15×15		2.022	0.79923	1.50925	0.9136
			20×20		2.1305	0.84212	1.5255	0.96072
			25×25		2.1865	0.86425	1.53825	0.98093
70			5×5		0.675	0.26681	0.653	0.33882
			10×10		2.3615	0.93342	1.899	1.10312
			15×15		2.655	1.04944	1.9815	1.19946
			20×20		2.807	1.10952	2.00575	1.26317
			25×25		2.8775	1.13738	2.02525	1.29149
100	RQT9	0.25	5×5	120	0.33025	0.12922	0.268	0.14523
			10×10		1.437	0.56229	1.135	0.69441
			15×15		1.752	0.68555	1.233	0.79214
			20×20		1.865	0.72976	1.25375	0.84165
			25×25		1.9275	0.75422	1.26225	0.86319
90			5×5		0.435	0.17021	0.373	0.20212
			10×10		1.855	0.7259	1.436	0.87857
			15×15		2.1615	0.84578	1.52125	0.97732
			20×20		2.28275	0.89323	1.547	1.03851
			25×25		2.3635	0.92482	1.56175	1.06801
80			5×5		0.684	0.26765	0.541	0.293
			10×10		2.383	0.93245	1.844	1.12756
			15×15		2.7725	1.08486	1.93525	1.2426
			20×20		2.92325	1.14385	1.959	1.31435
			25×25		3.01775	1.18083	1.98025	1.35344
70			5×5		1.08175	0.42328	0.901	0.4879
			10×10		3.17725	1.24324	2.464	1.5066
			15×15		3.5915	1.40533	2.499	1.6045
			20×20		3.784	1.48066	2.53475	1.70054
			25×25		3.89825	1.52536	2.54725	1.74088
100	RQT10	0.3	5×5	150	0.525	0.2074	0.461	0.24845
			10×10		2.4425	0.96471	2.002	1.22307
			15×15		2.98375	1.17848	2.15625	1.39092
			20×20		3.17275	1.25313	2.187	1.48331
			25×25		3.28225	1.29638	2.2095	1.52934
90			5×5		0.81725	0.32279	0.641	0.34496
			10×10		3.211	1.2682	2.522	1.53851
			15×15		3.68075	1.45377	2.6425	1.7021

Table 3 (continued)

SSD (cm)	RQT	Added filtration (mmCu)	Field size (cm^2)	Potential (kV)	Mean charge (direct) (nC)	Entrance skin dose (ESD) (direct) (mGy)	Mean charge (indirect) (nC)	Entrance skin dose (ESD) (indirect) (mGy)
			20×20		3.898	1.53958	2.69825	1.8274
			25×25		4.03225	1.59261	2.7245	1.88307
80			5×5		1.10175	0.43516	0.865	0.46428
			10×10		4.06225	1.60449	3.28125	1.99641
			15×15		4.66	1.84058	3.37225	2.16643
			20×20		4.932	1.94802	3.41	2.30335
			25×25		5.085	2.00845	3.44775	2.37667
70			5×5		1.5365	0.60637	1.261	0.67694
			10×10		5.35075	2.11165	4.329	2.63433
			15×15		6.1285	2.41859	4.36325	2.80354
			20×20		6.45875	2.54892	4.41725	2.98422
			25×25		6.65875	2.62785	4.47775	3.0872

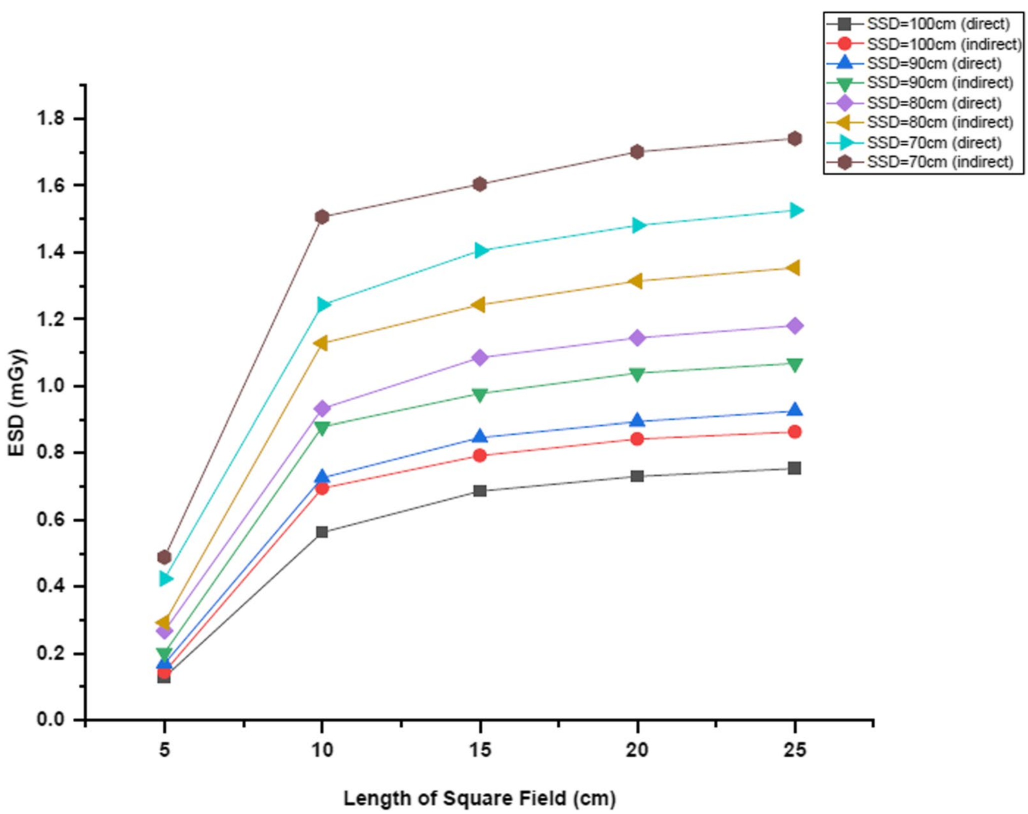

Fig. 5 Variation of ESD with field size for different SSDs using direct and indirect method (RQT9)

and indirect measurements of ESD is found to be in the range of 0.032% to 29.4% which is due to combined uncertainties in the values of backscatter factors and mass energy absorption coefficient ratios [3]. In the literature, this deviation was found to be 0% to 40% [4].

Discussion

Entrance skin dose (ESD) is considered to be an important parameter in assessing the patient dose in diagnostic radiology [15]. Medical diagnostic procedures are the largest contributor of patient radiation dose because globally every year large number of X-ray examinations

Table 4 Results of experiments

Sr. No	Radiation qualities	Added filtration (mm) (Al for RQAs and Cu for RQTs)	Effective energy (keV)	Tube potential	Estimated ESD (mGy)	% Deviation between direct and indirect methods
1	RQR2		26.9	40	0.025–0.253	0.032–14.08
2	RQR5		32.1	70	0.101–1.156	0.07–25.3
3	RQR8		37.8	100	0.216–2.426	3.5–15.02
4	RQR10		47.3	150	0.391–5.11	0.07–29.4
1	RAQ2	4.0	29.6	40	0.006–0.058	0.035–11.9
2	RQA5	21.0	49.2	70	0.0045–0.053	0.5–18.6
3	RQA8	34.0	65.2	100	0.0089–0.107	0.68–22.09
4	RQA10	45.0	86.1	150	0.0156–0.243	6.6–26.3
1	RQT8	0.20	50.7	100	0.105–1.137	9.1–26.9
2	RQT9	0.25	56.9	120	0.129–1.525	9.5–23.5
3	RQT10	0.30	65.3	150	0.207–2.627	6.6–26.8

are performed [8]. In order to optimize the patient dose, the quantity to be monitored per radiograph as a diagnostic reference level is ESD as recommended by European commission (EC 1996) [9, 15]. The aim of this study was to investigate the ESD per examination for different field sizes and SSDs for diagnostic radiation qualities RQRs, RQAs and RQTs using direct and indirect methods of measurement. The diagnostic X-ray qualities were selected according to scheme given in TRS-457. Shadow-free diagnostic (SFD) chamber was used for X-ray measurements. Water phantom was used as a backscatter source for direct measurements. Alignment of chamber, phantom and central beam axis was achieved using laser alignment systems. ESD was plotted against field sizes and SSDs, and the corresponding variations were analyzed. The deviation between direct and indirect method was also reported. Out of selected diagnostic X-ray qualities, maximum ESD values occur at SSD 70 cm and field size $25 \times 25 cm^2$. For RQR10, it is 5.12 mGy (direct), while for RQA10, it is 0. 244 mGy. Average energy value for RQA10 is 86.1 keV, while for RQR10 it is 47.3 keV. BSF values for all field sizes increase with incident beam energy and reach a maximum value between 50 and 70 keV; for higher energies (>70keV), it decreases [13]. This is the possible reason for ESD value lower for RQA10 as compared to RQR10. The maximum ESD is observed to be 2.63 mGy for RQT10 at SSD of 70 cm and field size $25 \times 25 cm^2$.

ESD values for RQAs and RQTs are lower than RQRs because added filtration absorbs the soft X-rays which would otherwise contribute to ESD. Radiation doses received by the patients in diagnostic X-ray examinations are below the doses that can cause deterministic effects, but these small doses can cause stochastic effects according to linear to threshold (LNT) model. We have to take into account the ALARA principle which states that all exposures must be given as low as reasonably achievable. According to European Commission (EC) 1996, the most preferred quantity to be monitored per radiograph is entrance skin dose (ESD) [4].

ESD is reported in the literature as a dose descriptor to quantify diagnostic reference levels (DRLs) or guidance doses. These DRLs or guidance doses are described in European Commission (EC 1996). These DRLs help in optimizing the radiation dose to patients and also ensure good practice for X-ray examinations.

Table 5 Comparison of some selected present data with published data

Examination type	kV	mAs	Field size (cm^2)	SSD (cm)	ESD (mGy)
Cervical spine LAT [14]	65	36	55×53	153	0.62
Cervical spine AP [14]	65	36	51×45	103	1.12
PA chest [15]	101	9	51×45	170	0.20
Pelvis [3]	72	22	51×45	88	1.21
Abdomen [3]	70	13	51×45	78	1.62
Lumber spine AP [3]	68	13	51×45	80	1.50
Wrist joint [14]	42	4.6	13×13	82	0.04
Perform on water phantom (present work)	70	10	25×25	100	0.56
	70	10	25×25	100	0.56
	100	10	25×25	100	1.19
	70	10	25×25	90	0.69
	70	10	25×25	80	0.88
	70	10	15×15	80	0.84
	40	10	10×10	80	0.16
	40	10	15×15	80	0.18

Comparison of present data with some published literature is shown in Table 5. As present study was performed on water phantom, exact comparison cannot be made with the clinical scenarios which is the limitation of this study, but present work can be used by the radiology departments who are setting their diagnostic reference levels (DRLs) in the field of diagnostic radiology. Deviation between direct and indirect method for ESD measurement is shown in Table 4 for different radiation qualities given in TRS-457. Tables 1, 2, 3, 4 and 5 show that ESD depends on beam energy, tube voltage, tube current, exposure time, field size and SSD. ESD increases with increasing filed sizes and decreasing SSDs. This study for the calculation of ESD for diagnostic X-rays (RQRs, RQAs and RQTs) will help in establishing diagnostic reference levels (DRLs) in diagnostic radiology department. It will also help the radiographers to optimize field sizes, SSDs, tube voltage and tube current which will help in optimizing the dose to the patients, ensuring good practice and thereby reducing the stochastic risk through ionizing radiations.

Conclusions

This study takes into account ESD variations with SSD and field size for diagnostic X-ray machine available at SSDL of Pakistan. Results of this study show good agreement with relevant studies, and these may be used as a baseline data for establishment of local diagnostic reference levels. Choice of X-ray examination parameters like tube voltage (kV), current (mA), exposure time (sec), SSD and field size during planer X-ray examinations has to be optimized so as to minimize ESD, and this will reduce the stochastic risk to the patients.

Recommendations

It is recommended that ESD data of present study can be used for the calculation of effective dose (ED) using corresponding mGy to mSv conversion factors for use in radiation protection purposes in radiology departments. It is also recommended that ESD values given in this work can be used for comparison with corresponding values obtained either with torso and anthropomorphic phantoms or planar X-ray examinations. ESD measurements with thermoluminescent dosimeters (TLDs) are also recommended which are cheap and easily available.

Abbreviations

ESD	Entrance skin dose
SFD chamber	Shadow-free diagnostic chamber
SSD	Source to surface distance
BSF	Backscatter factor
SSDL	Secondary standard dosimetry laboratory
ICRU	International Commission on Radiation Units and Measurements
ICRP	International Commission on Radiological Protection
DRL	Diagnostic reference level
CT	Computed tomography
IAEA	International Atomic Energy Agency
BSS	Basic safety standard

Acknowledgements

We are thankful to all working members of Health Physics Division of Pakistan Institute of Nuclear Science and Technology (PINSTECH) and Pakistan Institute of Engineering and Applied Sciences (PIEAS) for their continuous support in the form of technical facilities which we realized during the course of the research work.

Author contributions

Umar Hussain Haider performed all measurements stated in the research article. Babar Hussain as a supervisor provided all experimental facilities and technical support. He also helped in arranging experimental setup for all the measurements. Wajeeha Shaheen helped in analyzing the results. Shakeel Ur Rehman as a co-supervisor helped in making the manuscript final. All authors read and approved the final manuscript.

Funding

There is no funding for this research.

Availability of data and materials

The authors declare that the data used in this article which supports our findings are given in the reference list of the manuscript. DOIs are also provided.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Received: 28 September 2023 Accepted: 18 August 2024
Published online: 26 August 2024

References

1. Tung C, Lee C, Tsai H, Tsai S, Chen I (2008) Body size-dependent patient effective dose for diagnostic radiography. Radiat Meas 43(2–6):1008–1011
2. Akbas U, Donmez Kesen N, Koksal C, Bilge H (2016) Surface and buildup region dose measurements with markus parallel-plate ionization chamber, GafChromic EBT3 film, and MOSFET detector for high-energy photon beams. Adv High Energy Phys 2016:1
3. Aliasgharzadeh A, Mihandoost E, Masoumbeigi M, Salimian M, Mohseni M (2015) Measurement of entrance skin dose and calculation of effective dose for common diagnostic X-ray examinations in Kashan, Iran. Global J Health Sci 7(5):202
4. Musa Y, Hashim S, Karim MKA (2019) Direct and indirect entrance surface dose measurement in X-ray diagnostics using nanodot osl dosimeters. J Phys Conf Ser 1248(1):012014
5. Yeung A (2019) The as low as reasonably achievable' (Alara) principle: a brief historical overview and a bibliometric analysis of the most cited publications. Radioprotection 54(2):103–109
6. Sharma R, Sharma SD, Pawar S, Chaubey A, Kantharia S, Babu D (2015) Radiation dose to patients from X-ray radiographic examinations using computed radiography imaging system. J Med Phys Assoc Med Phys India 40(1):29
7. Sonawane A, Shirva V, Pradhan A (2010) Estimation of skin entrance doses (SEDS) for common medical X-ray diagnostic examinations in India

and proposed diagnostic reference levels (DRLS). Radiat Prot Dosimetry 138(2):129–136
8. Sharma SD, Sharma R, Mulchandani U, Chabey A, Chourasia G, Mayya Y (2013) Measurement of entrance skin dose for diagnostic X-ray radiographic examinations and establishment of local diagnostic reference levels. In World congress on medical physics and biomedical engineering May 26–31, 2012, Beijing, China, vol. 39. Springer, pp 860–863
9. Taha M, Al-Ghorabie F, Kutbi R, Saib W (2015) Assessment of entrance skin doses for patients undergoing diagnostic X-ray examinations in King Abdullah Medical City, Makkah, KSA. J Radiat Res Appl Sci 8(1):100–103
10. Edmonds K (2009) Diagnostic reference levels as a quality assurance tool. Radiographer 56(3):32–37
11. F. Pernicka and I. McLean, *Dosimetry in diagnostic radiology: an international code of practice*. International Atomic Energy Agency, page 70, technical report series no. 457, 2007.
12. Omrane LB, Verhaegen F, Chahed N, Mtimet S (2003) An investigation of entrance surface dose calculations for diagnostic radiology using Monte Carlo simulations and radiotherapy dosimetry formalisms. Phys Med Biol 48(12):1809
13. Benmakhlouf H, Bouchard H, Fransson A, Andreo P (2011) Backscatter factors and mass energy-absorption coefficient ratios for diagnostic radiology dosimetry. Phys Med Biol 56(22):7179. https://doi.org/10.1088/0031-9155/56/22/012
14. Wambersie A, Zoetelief J, Menzel H, Paretzke H (2005) The icru (international commission on radiation units and measurements): its contribution to dosimetry in diagnostic and interventional radiology. Radiat Prot Dosim 117(1–3):7–12
15. Compagnone G, Pagan L, Bergamini C (2005) Comparison of six phantoms for entrance skin dose evaluation in 11 standard X-ray examinations. J Appl Clin Med Phys 6(1):101–113