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Reduction of radiation risks in patients undergoing some X-ray examinations by using optimal projections: A Monte Carlo program-based mathematical calculation

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ABSTRACT

The objectives of this paper were calculation and comparison of the effective doses, the risks of exposure-induced cancer, and dose reduction in the gonads for male and female patients in different projections of some X-ray examinations. Radiographies of lumbar spine [in the eight projections of anteroposterior (AP), posteroanterior (PA), right lateral (RLAT), left lateral (LLAT), right anterior-posterior oblique (RAO), left anterior-posterior oblique (LAO), right posterior-anterior oblique (RPO), and left posterior-anterior oblique (LPO)], abdomen (in the two projections of AP and PA), and pelvis (in the two projections of AP and PA) were investigated. A solid-state dosimeter was used for the measuring of the entrance skin exposure. A Monte Carlo program was used for calculation of effective doses, the risks of radiation-induced cancer, and doses to the gonads related to the different projections. Results of this study showed that PA projection of abdomen, lumbar spine, and pelvis radiographies caused 50%-57% lower effective doses than AP projection and 50%-60% reduction in radiation risks. Also use of LAO projection of lumbar spine X-ray examination caused 53% lower effective dose than RPO projection and 56% and 63% reduction in radiation risk for male and female, respectively, and RAO projection caused 28% lower effective dose than LPO projection and 52% and 39% reduction in radiation risk for males and females, respectively. About dose reduction in the gonads, using of the PA position rather than AP in the radiographies of the abdomen, lumbar spine, and pelvis can result in reduction of the ovaries doses in women, 38%, 31%, and 25%, respectively and reduction of the testicles doses in males, 76%, 86%, and 94%, respectively. Also for oblique projections of lumbar spine X-ray examination, with employment of LAO rather than RPO and also RAO rather than LPO, demonstrated 22% and 13% reductions to the ovaries doses and 66% and 54% reductions in the testicles doses, respectively.

Key words: Optimal projections, radiation risks reduction, X-ray examinations

Introduction

Radiological examinations while being highly helpful in the diagnosis of disease but may involve potential risks,

such as carcinogenic effects and genetic effects.^[1,2] While modern nonionizing imaging systems such as magnetic resonance imaging offer undeniable advantages including lack of radiation and better image quality, the conventional X-ray examinations will still remain prevalent in diagnosis, because they are more available and cheaper than others. For example, lumbar spine X-ray examination contributes to 15% of the collective dose from diagnostic X-ray examinations, after computerized tomography.^[3] Therefore, the radiation dose delivered to a patient must be kept as low as reasonably achievable (ALARA principle). For achieving this purpose, a number of studies had tried to decrease the patient dose by increasing kVp^[4] or FFD,^[5] and using of an air gap.^[6] However, one of the most efficient dose reducing methods requiring no additional cost is the use of optimized projections instead of the traditionally accepted projections.

Some studies have found that posteroanterior (PA) projection instead of anteroposterior (AP) projection

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decrease the patient dose for radiographies of the scoliosis,^[7] abdomen,^[8,9] the pelvis,^[10] the clavicle,^[11] and the lumbar spine.^[3,12,13] In these investigations, the effective dose was mostly used for comparison of different projections. However, the utilization of the effective dose in expressing the stochastic harm to patients from ionizing radiation is sometimes criticized due to the inherent uncertainties and oversimplifications involved.^[1,14,15] It was recommended that the risk coefficients from the Biologic Effects of Ionizing Radiation, National Academy of Sciences, 2006 (BEIR VII) Report^[2] used to perform risk estimates. The BEIR VII committee has derived risk models which take into account organ specific dose, the cancer site, sex, and age at the exposure. Also, the previous studies have not compared the dose reduction in the gonads in different projections.

Therefore, the aims of the present study were the calculation and comparison of the effective doses and the risks of exposure induced cancer of male and female patients in different projections of the abdomen, the pelvis, and the lumbar spine X-ray examinations. The gonad absorbed doses were also calculated for comparison of hereditary effects in different projections of the mentioned radiographies.

Materials and Methods

The studied X-ray examinations

The investigated radiographic examinations included: Radiographies of lumbar spine [in the eight projections of AP, PA, right lateral (RLAT), left lateral (LLAT), right anterior-posterior oblique (RAO), left anterior-posterior oblique (LAO), right posterior-anterior oblique (RPO) and left posterior-anterior oblique (LPO)], abdomen (in the two projections of AP and PA), and pelvis (in the two projections of AP and PA). The comparisons were carried out between PA and AP, RLAT and LLAT, LAO and RPO, as well as LPO and RAO projections, because these pair projections display similar anatomy and organs but in the opposite directions.

Measurement of the entrance skin exposure

A solid-state dosimeter (Model 6001 UNFORS) was used for the measuring of the ESE. The dosimeter was placed in the source to skin distance (SSD) associated to every projection in air without the patient presence. Then measurements were performed, while the exposure factors [X-ray tube voltage (kVp), tube current (mA), exposure time (s), SSD, radiation field size] associated to each projection were adjusted on the X-ray machines [Table 1]. This work was performed for the four different X-ray units selected in the radiology departments of the Yazd hospitals. These X-ray units were from Varian, Toshiba, General Electric, and Siemens which their total filtration ranged from 1.5 to 2.5 mm AL. Total filtration for the different X-ray units was measured by the X-ray multimeter (Model Barracuda). The appropriate and real exposure factors related to the different X-ray units

for executing the mentioned radiographies of a standard patient were asked from the expert technologists. The standard patient was considered in this study had a height of 178.6 cm and a weight of 73.2 kg which was usually utilized in the literature.^[16]

Calculation of effective dose and risk of exposure-induced cancer death

For the calculation of effective dose and the REID related to the different projections, an analytical simulation study was performed. To achieve this purpose, the PC-based Monte Carlo program (PCXMC) (version 2.0)^[17] developed by STUK (Radiation and Nuclear Safety Authority in Finland), was used.

The PCXMC code automatically generated the x-ray spectrum, based on the real input parameters (kVp, total filtration, etc). During the simulation, the maximum energy of photons was set 100 (KeV) and the number of photon particles tracked was 1000000. The dose calculation method used in this software was based on the Monte Carlo simulation, which was according to stochastic mathematical of interactions between photons and matter. The PCXMC calculated both organ doses for a large number of organs/tissues and the resulting effective dose to the patient by using anatomical data from the mathematical phantom models. The program calculated the effective dose based on the tissue weighting factors of ICRP Publication 103.^[1] The required input data for these calculations included: definition of all projections (location and size of the radiation field and projection angle) and the exposure factors (kVp, ESE, and total filtration) relating to different X-ray examinations. Performance and simulation of each X-ray projection was

Table 1: The range of appropriate and real exposure factors related to the different X-ray units which used for executing the different radiographies of a standard patient

Examination	Projection	kVp	mAs	Source to skin distance (SSD) (cm)	Radiation field size (cm ²)
Abdomen	AP	64-70	50-60	75	33×40
	PA	64-70	50-60	75	33×40
Lumbar spine	AP	64-70	50-60	75	20×40
	PA	64-70	50-60	75	20×40
	RLAT	78-88	60-80	55	14×18
	LLAT	78-88	60-80	55	14×18
	RPO	72-80	54-70	70	21×28
	LAO	72-80	54-70	70	21×28
	LPO	72-80	54-70	70	21×28
	RAO	72-80	54-70	70	21×28
Pelvis	AP	64-70	50-60	75	33×26
	PA	64-70	50-60	75	33×26

AP: Anteroposterior, LAO: Left anterior-posterior oblique, LLAT: Left lateral, LPO: Left posterior-anterior oblique, PA: Posteroanterior, RAO: Right posterior-anterior oblique, RLAT: Right lateral, RPO: Right posterior-anterior oblique, SSD: source to skin distance

based on standard guidelines, for example, Merrill's atlas of radiographic positioning and procedures.^[18] After entering the above data into the program, the radiation doses received by the organs and resultant effective doses were obtained for every projection of each examination.

The PCXMC program also calculated the REID using the calculated organ doses and their corresponding cancer estimates. These estimations were based on the risk models of BEIR VII committee.^[2] Risk estimates were associated to the excess of fatal cancers over those naturally occurring in the population. The program calculated the risk of exposure-induced death for leukemia, cancers in colon, stomach, lung, urinary bladder, prostate, uterus, ovaries, breast, liver, thyroid, and for all other solid cancers combined. A more explanation of the details of the program for this topic can be found in a technical program document.^[17]

Calculation of the gonad-absorbed doses

The calculations of the gonad-absorbed doses were also performed by the PCXMC program. The ovaries-absorbed doses for female and the testicles-absorbed doses for male were used for comparison of hereditary effects of different projections in the mentioned radiographies.

Statistical analysis

The data analysis was performed with the Statistical Package for the Social Sciences software (SPSS, version 19.0, by the SPSS, USA). A t-test was used for comparison of differences in data obtained for each pair projections. The differences were statistically significant, if *P* value was less than 0.05.

Results

Table 2 showed the comparisons of absorbed doses of the different significant organs or tissues for each projection related to the different X-ray examinations. Active bone marrow, breasts (women), colon, liver, lungs, ovaries (women), prostate (men), stomach, uterus (women), and urinary bladder are tissues that more exposed in these X-ray examinations.

Tables 3 and 4 also illustrated the comparisons of risk of the different cancers in the different X-ray examinations for male and female patients, respectively. The different cancer risk estimates are mostly based on doses of different organ or tissues presented in Table 2.

Comparison of the mean values of the effective dose and REID for each projection of the different X-ray examinations were given in Table 5. The REID values are the sum of the risks of the various cancers which displayed in Tables 3 and 4. The word "mean" refers to averaging of results obtained for the four X-ray machines used in this study. In other word, the different cancer risks and final REID related to every

projection were separately calculated for every X-ray machines and then the mean of the obtained values were displayed in these tables. This information demonstrated the preferable projections for effective dose and radiation risk reduction.

According to these results, significant effective dose and radiation risk reduction were observed in the PA position compared with the AP position for radiographies of abdomen, lumbar spine, and pelvis. For oblique positions of lumbar spine radiography, Table 5 also showed that the RPO projection causes a higher effective dose and radiation risk compared with the LAO projection as well as the LPO projection causes a higher effective dose and radiation risk compared with the RAO. Table 5 also illustrated that radiation risk reduction in the LLAT is higher than the RLAT in the male patients.

The mean values of gonad absorbed doses for each projection related to the different X-ray examinations are given in Table 6. The ovaries-absorbed doses for female and the testicles-absorbed doses for male can be used for choice of appropriate projections of the mentioned radiographies, so that the genetic effects are minimized.

Discussion

The results of this study showed that using of appropriate positions during X-ray examinations of abdomen, lumbar spine, and pelvis could be reduced the stochastic harm to patients from ionizing radiation. In the present study, in addition of the effective dose which had been calculated in other studies, the REID values were separately estimated for various projections, for males and females. Furthermore, further projections especially for lumbar spine were investigated in comparison with the previous studies which had only studied a few projections. The gonad-absorbed doses were also calculated for comparison of hereditary effects of radiation in different projections of the mentioned radiographies.

In the other studies, the comparison between AP and PA projections of radiographies of the abdomen,^[8,9] lumbar spine,^[3,12,13] pelvis,^[10] and clavicle^[11] had been done but there were not any comparison between the left and right lateral lumbar (RLAT and LLAT) and any comparison between the oblique projections of the lumbar spine radiography in the literature.

The second version of the simulation program (PCXMC) employed in this study was not used in the previous similar studies, although it was used in the other studies^[21,22] for different purposes. It had some advantages such as calculation of the effective dose using the new tissue weighting factors introduced in ICRP Publication 103^[11] and also estimation of the REID for males and females, separately. Therefore, the new and interesting results were obtained with these particular features.

Table 2: The comparisons of absorbed doses (mSv) of the different organs or tissues for each projection related to the different X-ray examinations

Examination	Projection	Organ type	Active bone marrow	Breasts (women)	Colon	Liver	Lungs	Ovaries (women)	Prostate (men)	Stomach	Uterus (women)	Urinary bladder
Abdomen	AP	The mean dose	0.170	0.019	1.013	0.896	0.042	0.732	0.980	1.439	0.938	1.706
		±SD	0.035	0.004	0.216	0.197	0.008	0.149	0.212	0.321	0.196	0.382
	PA	The mean dose	0.530	0.006	0.371	0.440	0.040	0.456	0.236	0.241	0.424	0.238
		±SD	0.114	0.001	0.073	0.093	0.008	0.091	0.046	0.048	0.083	0.046
	Dose reduction (%)		-211.63 ^a	67.23	63.35	50.83	5.47	37.77	75.87	83.24	54.82	86.04
							(<i>P</i> >0.05) ^b					
Lumbar spine	AP	The mean dose	0.117	0.014	0.902	0.633	0.035	0.613	1.045	1.196	0.910	1.690
		±SD	0.024	0.003	0.193	0.139	0.007	0.126	0.226	0.267	0.191	0.379
	PA	The mean dose	0.486	0.005	0.329	0.237	0.031	0.423	0.268	0.204	0.413	0.235
		±SD	0.104	0.001	0.065	0.049	0.006	0.083	0.053	0.040	0.082	0.047
	Dose reduction (%)		-314.44	65.95	63.47	62.53	9.52	30.86	74.30	82.96	54.63	86.07
	R LAT	The mean dose	0.570	0.030	1.019	0.084	0.256	0.719	0.262	1.431	0.438	0.298
		±SD	0.123	0.007	0.226	0.022	0.054	0.170	0.067	0.305	0.108	0.074
	L LAT	The mean dose	0.566	0.034	0.830	3.068	0.288	0.751	0.312	0.086	0.428	0.307
		±SD	0.122	0.008	0.183	0.607	0.061	0.177	0.078	0.023	0.107	0.076
	Dose reduction (%)		0.77	-11.03	18.49	-3536.18	-12.70	-4.45	-19.14	94.00	2.30	-3.17
				(<i>P</i> >0.05)	(<i>P</i> >0.05)	(<i>P</i> >0.05)	(<i>P</i> >0.05)	(<i>P</i> >0.05)	(<i>P</i> >0.05)		(<i>P</i> >0.05)	(<i>P</i> >0.05)
	RPO	The mean dose	0.203	0.018	1.201	0.373	0.034	0.889	0.200	2.500	1.109	1.307
		±SD	0.039	0.003	0.221	0.070	0.007	0.170	0.040	0.445	0.208	0.235
	LAO	The mean dose	0.722	0.005	0.472	0.487	0.030	0.695	0.102	0.177	0.579	0.223
		±SD	0.132	0.001	0.093	0.090	0.006	0.141	0.022	0.038	0.116	0.046
	Dose reduction (%)		-255.57	69.26	60.72	-30.49	12.25	21.83	48.85	92.94	47.75	82.97
							(<i>P</i> >0.05)	(<i>P</i> >0.05)				
	LPO	The mean dose	0.203	0.018	1.289	1.789	0.037	0.898	0.219	0.581	1.094	1.287
		±SD	0.039	0.004	0.236	0.318	0.008	0.173	0.042	0.108	0.205	0.231
	RAO	The mean dose	0.746	0.005	0.494	0.263	0.031	0.778	0.103	0.406	0.598	0.238
		±SD	0.136	0.001	0.098	0.052	0.006	0.155	0.022	0.078	0.120	0.049
	Dose reduction (%)		-267.31	71.50	61.64	85.27	15.49	13.40	53.08	30.00	45.32	81.55
							(<i>P</i> >0.05)	(<i>P</i> >0.05)				
	Pelvis	AP	The mean dose	0.107	0.002	0.698	0.017	0.001	0.622	1.129	0.032	0.912
±SD			0.021	0.000	0.149	0.003	0.000	0.127	0.243	0.006	0.192	0.384
PA		The mean dose	0.380	0.000	0.306	0.012	0.000	0.465	0.348	0.015	0.432	0.271
		±SD	0.082	0.000	0.060	0.002	0.000	0.092	0.069	0.003	0.086	0.053
Dose reduction (%)		-253.60	88.98	56.23	31.42	27.11	25.18	69.17	52.89	52.60	84.26	

^aNegative values indicate increase in absorbed dose of that organ or tissue in the second projection in compared with the first projection. ^bDose reduction values which are specified as (*P*>0.05), evaluation of differences between the two projections isn't statistically significant. AP: Anteroposterior; LAO: Left anterior-posterior oblique, LLAT: Left lateral, LPO: Left posterior-anterior oblique, PA: Posteroanterior, RAO: Right posterior-anterior oblique, RLAT: Right lateral, RPO: Right posterior-anterior oblique, SD: Standard deviation

The results in Table 5 show that using of effective dose alone cannot be sufficient in some cases. In Table 5, comparison of the effective dose reductions and the radiation risk reductions in men and women due to the projection variations showed three situations. In the first situation, there was the agreement between the effective dose and radiation risk reduction, but there was not a significant difference between men and women. This situation was observed between AP and PA projections in abdomen X-ray examination that PA projection caused 50% (*P* = 0.001) lower effective dose than AP projection and 56% (*P* = 0.001) and 57% (*P* = 0.001) reduction in radiation risk for male and female, respectively and there were no significant differences between men and women. Similarly, the use of the PA projection during lumbar spine

resulted in a reduction of 51% (*P* = 0.001) in effective dose and 58% (*P* = 0.001) in radiation risk for both male and female. These results were in general agreement with previous studies, where PA projections significantly reduced the effective dose for abdominal examinations. [3,8,9,12,13]

In the second situation, there was the agreement between the effective dose and radiation risk reduction and there was a significant difference between men and women. This situation was observed between oblique projections in lumbar spine X-ray examination that LAO projection caused 53% (*P* < 0.001) lower effective dose than RPO projection and 56% (*P* < 0.001) and 63% (*P* < 0.001) reduction in radiation risk for male and female, respectively, and RAO projection caused 28% (*P* = 0.01) lower effective dose than

Table 3: The comparisons of risk of the different cancers for male patients in the different X-ray examinations

Examination	Projection	Cancer type	Leukemia	Colon	Liver	Lung	Stomach	Bladder	Other solid cancers	
Abdomen	AP	The mean values of risk (per million)	0.56	4.32	5.05	0.34	7.10	2.57	1.89	
		±SD	0.11	0.92	1.11	0.07	1.58	0.57	0.40	
	PA	The mean values of risk (per million)	1.75	1.59	2.48	0.32	1.19	0.36	1.99	
		±SD	0.38	0.31	0.52	0.06	0.24	0.07	0.43	
	Risk reduction (%)			-212.36 ^a	63.33	50.84	5.49 (<i>P</i> >0.05) ^b	83.21	86.04	-5.42 (<i>P</i> >0.05)
	Lumbar spine	AP	The mean values of risk (per million)	0.39	3.85	3.57	0.28	5.90	2.54	2.02
±SD			0.08	0.82	0.78	0.05	1.32	0.57	0.43	
PA		The mean values of risk (per million)	1.61	1.41	1.34	0.25	1.00	0.35	1.79	
		±SD	0.34	0.28	0.27	0.05	0.20	0.07	0.38	
Risk reduction (%)			-314.46	63.51	62.54	9.57 (<i>P</i> >0.05)	82.96	86.05	11.26 (<i>P</i> >0.05)	
R LAT		The mean values of risk (per million)	1.88	4.35	0.48	2.07	7.05	0.45	3.30	
±SD		0.41	0.96	0.13	0.44	1.51	0.11	0.70		
L LAT		The mean values of risk (per million)	1.87	3.55	17.33	2.33	0.42	0.46	1.93	
±SD		0.40	0.78	3.41	0.49	0.12	0.11	0.43		
Risk reduction (%)			0.80 (<i>P</i> >0.05)	18.41 (<i>P</i> >0.05)	-3539.71	-12.70 (<i>P</i> >0.05)	94.00	-3.18 (<i>P</i> >0.05)	41.62	
RPO		The mean values of risk (per million)	0.67	5.12	2.11	0.27	12.32	1.97	1.90	
±SD		0.13	0.94	0.39	0.06	2.20	0.36	0.35		
LAO		The mean values of risk (per million)	2.38	2.01	2.74	0.24	0.87	0.34	2.22	
±SD		0.44	0.40	0.51	0.05	0.19	0.07	0.40		
Risk reduction (%)			-255.36	60.76	-30.29	12.24 (<i>P</i> >0.05)	92.92	82.97	-16.56 (<i>P</i> >0.05)	
LPO		The mean values of risk (per million)	0.67	5.50	10.09	0.30	2.86	1.94	1.75	
±SD		0.13	1.01	1.80	0.06	0.53	0.35	0.33		
RAO		The mean values of risk (per million)	2.46	2.11	1.49	0.25	2.00	0.36	2.54	
±SD	0.45	0.42	0.29	0.05	0.39	0.07	0.46			
Risk reduction (%)			-267.30	61.66	85.28	15.41 (<i>P</i> >0.05)	30.07	81.52	-45.42	
Pelvis	AP	The mean values of risk (per million)	0.35	2.98	0.10	0.00	0.16	2.59	3.48	
		±SD	0.07	0.63	0.02	0.00	0.03	0.58	0.82	
	PA	The mean values of risk (per million)	1.25	1.30	0.07	0.00	0.08	0.41	0.64	
		±SD	0.27	0.26	0.01	0.00	0.01	0.08	0.13	
	Risk reduction (%)			-254.06	56.33	31.39	27.12	52.90	84.26	81.73

^aNegative values indicate increase in risk of cancer in the second projection in compared with the first projection. ^bRisk reduction values which are specified as (*P*>0.05), evaluation of differences between the two projections is not statistically significant. AP: Anteroposterior; LAO: Left anterior-posterior oblique; LLAT: Left lateral; LPO: Left posterior-anterior oblique, PA: Posteroanterior, RAO: Right posterior-anterior oblique, RLAT: Right lateral, RPO: Right posterior-anterior oblique, SD: Standard deviation

LPO projection and 52% (*P* = 0.001) and 39% (*P* = 0.002) reduction in radiation risk for male and female, respectively. In the pelvis X-ray examination, this situation was also observed that PA projection caused 57% (*P* = 0.001) lower effective dose than AP projection and 61% (*P* = 0.001) and 50% (*P* = 0.001) reduction in radiation risk for male and female, respectively, so in three comparisons, there were significant differences between men and women (*P* < 0.05). In the third situation, there was not complete agreement between the effective dose and radiation risk reduction in men and women. It was observed in the right and left lateral positions of the lumbar spine radiography, while there was a nonsignificant 19% (*P* = 0.125) reduction in the effective dose in left relative to right lateral, however,

related to radiation risk, a 42% (*P* = 0.019) enhancement for men and a nonsignificant 9% (*P* = 0.482) reduction for women were obtained. These differences could be first, due to different absorbed doses which the various organs received in right or left lateral projection, and second, due to differences in the risk of exposure-induced cancer in men and women. Generally in all of radiographic projections, the risk of radiation-induced carcinogenesis will be lower if the sensitive organs are located farther from the X-ray tube. Also another reason for these reductions is that these organs are shielded by other structures such as bones of pelvis and lumbar spine. Evaluation of the results presented in Tables 2 to 4 confirmed these facts. For example, negative values of dose reduction for the active bone marrow in Table 2

Table 4: The comparisons of risk of the different cancers for female patients in the different X-ray examinations

Examination	Projection	Cancer type	Leukemia	Breast	Colon	Liver	Lung	Ovary	Stomach	Bladder	Other solid cancers	
Abdomen	AP	The mean values of risk (per million)	0.43	0.14	2.79	2.31	0.72	0.65	8.64	2.89	2.06	
		±SD	0.09	0.03	0.59	0.51	0.14	0.13	1.93	0.64	0.44	
	PA	The mean values of risk (per million)	1.33	0.05	1.02	1.14	0.68	0.40	1.45	0.40	2.41	
		±SD	0.29	0.01	0.20	0.24	0.13	0.08	0.29	0.08	0.52	
	Risk reduction (%)			-211.48 ^a	67.19	63.36	50.83	5.48	37.75	83.24	86.03	-17.40
				($P > 0.05$) ^b								
Lumbar spine	AP	The mean values of risk (per million)	0.29	0.10	2.48	1.63	0.59	0.54	7.18	2.86	1.81	
		±SD	0.06	0.02	0.53	0.36	0.12	0.11	1.60	0.64	0.38	
	PA	The mean values of risk (per million)	1.22	0.04	0.91	0.61	0.53	0.38	1.22	0.40	2.13	
		±SD	0.26	0.01	0.18	0.13	0.11	0.07	0.24	0.08	0.45	
	Risk reduction (%)			-315.18	65.95	63.46	62.53	9.53	30.85	82.99	86.07	-17.57
				($P > 0.05$)								
	R LAT	The mean values of risk (per million)	1.43	0.22	2.80	0.22	4.37	0.64	8.58	0.50	3.97	
		±SD	0.31	0.05	0.62	0.06	0.93	0.15	1.82	0.12	0.84	
	L LAT	The mean values of risk (per million)	1.42	0.25	2.28	7.92	4.92	0.67	0.52	0.52	2.29	
		±SD	0.31	0.06	0.50	1.56	1.04	0.16	0.14	0.13	0.51	
	Risk reduction (%)			0.82	-10.99	18.55	-3534.9	-12.65	-4.43	93.99	-3.22	42.32
	RPO	The mean values of risk (per million)	0.51	0.13	3.31	0.96	0.58	0.79	15.00	2.21	2.53	
		±SD	0.10	0.02	0.61	0.18	0.12	0.15	2.65	0.40	0.47	
	LAO	The mean values of risk (per million)	1.81	0.04	1.30	1.26	0.51	0.62	1.06	0.38	2.81	
		±SD	0.33	0.01	0.26	0.23	0.11	0.13	0.23	0.08	0.51	
	Risk reduction (%)			-255.74	69.25	60.72	-30.26	12.24	21.82	92.93	82.97	-11.28
				($P > 0.05$)								
	LPO	The mean values of risk (per million)	0.51	0.13	3.55	4.61	0.63	0.80	3.48	2.18	2.34	
		±SD	0.10	0.03	0.65	0.82	0.13	0.15	0.65	0.39	0.43	
	RAO	The mean values of risk (per million)	1.87	0.04	1.36	0.68	0.53	0.69	2.44	0.40	3.20	
		±SD	0.35	0.01	0.27	0.13	0.11	0.14	0.47	0.08	0.58	
	Risk reduction (%)			-267.52	71.52	61.71	85.26	15.50	13.39	29.94	81.55	-37.04
				($P > 0.05$)								
	Pelvis	AP	The mean values of risk (per million)	0.27	0.02	1.92	0.04	0.01	0.55	0.19	2.91	0.87
±SD			0.05	0.00	0.41	0.01	0.00	0.11	0.04	0.65	0.19	
PA		The mean values of risk (per million)	0.95	0.00	0.84	0.03	0.01	0.41	0.09	0.46	0.61	
		±SD	0.20	0.00	0.17	0.01	0.00	0.08	0.02	0.09	0.13	
Risk reduction (%)			-253.43	88.97	56.23	31.40	27.07	25.22	52.90	84.27	29.80	

^aNegative values indicate increase in risk of cancer in the second projection in compared with the first projection. ^bRisk reduction values which are specified as ($P > 0.05$), evaluation of differences between the two projections isn't statistically significant. AP: Anteroposterior, LAO: Left anterior-posterior oblique; LLAT: Left lateral, LPO: Left posterior-anterior oblique, PA: Posteroanterior, RAO: Right posterior-anterior oblique, RLAT: Right lateral, RPO: Right posterior-anterior oblique, SD: Standard deviation

indicated increase in absorbed dose of that tissue in the PA projection in compared with the AP projection, because the active bone marrow in the bones of pelvis and lumbar spine is located closer to the X-ray tube in PA projections in compared with AP projections unlike the other organs such as colon, liver, lung, stomach, and bladder. However, the highest organ dose does not necessarily lead to the highest risk of exposure-induced cancer related to that organ, because the risk of exposure-induced cancer are estimated based on the organ sensitivity, cancer site, sex, and age at the exposure in addition of organ dose.

In Table 6, the dose received by the gonads in various positions of the abdomen, lumbar spine, and pelvis X-ray examinations were separately shown for men and women.

These findings had not been investigated in the previous studies. The dose received by the gonads can be used to estimate the hereditary risks arising from radiation for men and women in the reproductive age and this fact have also been confirmed in other studies especially in the recent report of ICRP (ICRP 121).^[19] Using of the PA position rather than AP in the radiographies of the abdomen, lumbar spine, and pelvis can result in reduction of the ovaries doses in women, 38% ($P = 0.005$), 31% ($P = 0.015$), and 25% ($P = 0.037$), respectively and reduction of the testicles doses in males, 76% ($P < 0.001$), 86% ($P < 0.001$), and 94% ($P < 0.001$), respectively. Also for oblique projections of lumbar spine X-ray examination, with employment of LAO rather than RPO and also RAO rather than LPO, demonstrated 22% ($P = 0.05$) reduction and a nonsignificant

13% ($P = 0.237$) reduction to the ovaries doses and 66% ($P < 0.001$) and 54% ($P = 0.001$) reductions in the testicles doses, respectively, but the significant difference was not observed in the received gonads doses in right and left lateral positions of the lumbar spine X- ray examination. Considering Table 6, it is obvious that the gonads doses reductions due to the mentioned changes in positioning are more tangible in men rather than women. The most important reason for these differences is that the testicles in males compared with ovaries in women are located in the anterior part of the body.

It is important to acknowledge that suggested positions may pose certain limitations such as reduction of image quality and patient comfort in acute injuries. However, some evaluations performed in the previous studies^[3,7,8,11]

demonstrated no significant reduction in the image quality between similar projections such as AP and PA. About the lateral and oblique projections, aim of these views is imaging of the lumbar spine that almost located in the central axis of the body and its situation does not change much in the mentioned projections. Only the locations of nontarget organs such as stomach, liver, and pancreas change in these projections. Then, the image quality of the lumbar spine does not degrade in the chosen projections. There is not any difference on the patient comfort, in left and right lateral projections of lumbar spine, because it does not matter whether the patient reposes on the right or left side. Also in the oblique views of the lumbar spine, patient should be stabilized in all of the four projections and there is no significant difference in the comfort of patient in any projection. Therefore with applying the selected

Table 5: The mean values of entrance skin exposure, effective dose, and risk of exposure-induced cancer death for each projection related to the different X-ray examinations

Examination	Projection	ESE (mGy)	±SD	Effective dose (mSv)	±SD	Effective dose reduction (%)	P value ^a	The mean values of the REID (per million)							
								Male	±SD	Risk reduction (%)	P value	Female	±SD	Risk reduction (%)	P value
Abdomen	AP	3.368	0.871	0.521	0.113	50	0.001	21.85	4.76	56	0.001	20.63	4.50	57	0.001
	PA	3.368	0.871	0.259	0.053			9.67	1.99			8.89	1.84		
Lumbar spine	AP	3.368	0.871	0.459	0.100	51	0.001	18.55	4.06	58	0.001	17.50	3.80	58	0.001
	PA	3.368	0.871	0.226	0.046			7.75	1.59			7.43	1.52		
	RLAT	9.920	1.765	0.557	0.121	19	0.125	19.55	4.25	-42	0.019	22.75	4.93	9	0.482
	LLAT	9.920	1.765	0.450	0.097			27.85	5.73			20.78	4.35		
	RPO	6.644	1.186	0.648	0.118	53	<0.001	24.33	4.40	56	<0.001	26.03	4.73	63	<0.001
	LAO	6.644	1.186	0.305	0.058			10.82	2.05			9.76	1.84		
	LPO	6.644	1.186	0.479	0.088	28	0.01	23.08	4.16	52	<0.001	18.23	3.31	39	0.002
	RAO	6.644	1.186	0.344	0.065			11.19	2.11			11.19	2.11		
Pelvis	AP	3.368	0.871	0.316	0.070	57	0.001	9.66	2.13	61	0.001	6.80	1.46	50	0.001
	PA	3.368	0.871	0.137	0.028			3.75	0.76			3.41	0.69		

^aP values represent evaluation of differences between the two projections and indicate statistically significant differences between them if less than 0.05. AP: Anteroposterior, LAO: Left anterior-posterior oblique, LLAT: Left lateral, LPO: Left posterior-anterior oblique, PA: Posteroanterior, RAO: Right posterior-anterior oblique, REID: Risk of exposure-induced cancer death, RLAT: Right lateral, RPO: Right posterior-anterior oblique, SD: Standard deviation

Table 6: The mean values of gonad absorbed doses for each projection related to the different X-ray examinations

Examination	Projection	The mean doses to the gonads (mGy)							
		Ovaries	±SD	Dose reduction (%)	P value ^a	Testicles	±SD	Dose reduction (%)	P value
Abdomen	AP	0.732	0.149	38	0.005	0.152	0.032	76	<0.001
	PA	0.456	0.091			0.037	0.007		
Lumbar spine	AP	0.613	0.126	31	0.015	0.429	0.096	86	<0.001
	PA	0.423	0.083			0.062	0.012		
	RLAT	0.719	0.170	-4	0.751	0.049	0.013	-8	0.62
	LLAT	0.751	0.177			0.053	0.014		
	RPO	0.889	0.170	22	0.05	0.041	0.008	66	<0.001
	LAO	0.695	0.141			0.014	0.003		
	LPO	0.898	0.173	13	0.237	0.035	0.007	54	0.001
Pelvis	AP	0.778	0.155			0.016	0.004		
	PA	0.622	0.127	25	0.037	2.368	0.567	94	<0.001
		0.465	0.092			0.132	0.026		

^aP values represent evaluation of differences between the two projections and indicate statistically significant differences between them if less than 0.05. AP: Anteroposterior, LAO: Left anterior-posterior oblique, LLAT: Left lateral, LPO: Left posterior-anterior oblique, PA: Posteroanterior, RAO: Right posterior-anterior oblique, RLAT: Right lateral, RPO: Right posterior-anterior oblique

projections, the benefits from reduction of radiation risks are always greater than probable restrictions.

Another limitation of this study was the various random and systematic uncertainties embedded in estimates of cancers and cancer deaths induced by medical radiation. The extracted risks for low level of radiation exposures are based on the assumption of “linear nonthreshold” (LNT) model (in the low dose range, radiation doses greater than 0 will increase the risk of excess cancer and/or heritable disease in a simple proportionate manner). It seems to be little chance to prove or disprove LNT model in the near future. This subject was also discussed in article of Pradhan.^[20] However, that study also confirmed the optimization (ALARA) of the procedures to minimize the avoidable unnecessary radiation exposure. The aim of the present study was also choosing the optimal projection for performing the required X-ray examinations.

Conclusion

Results of this study introduced preferable projections for reduction of the effective dose, the risk of radiation-induced cancer, and gonad doses. Recommended projection, whenever possible, for abdomen and pelvis X-ray examinations should be the PA projection rather than AP projection. Also, suggested projections for lumbar spine radiography should be PA rather than AP, LAO rather than RPO, RAO rather than LPO, and for men, RLAT rather than LLAT.

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