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Reduction of Organ Absorbed Dose and Cancer Risk Through Optimizing the use of Projection in Diagnostic X-ray Examination

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Abstract

This study aimed to calculate and compare the estimated organ absorption dose, risk of cancer due to exposure, and dose received by the gonads for women and men in radio diagnostic examinations with different projections. Radiographic examination of the abdomen (with anterior-posterior (AP) and posterior-anterior (PA) projections) and lumbar vertebrae (with anterior-posterior projection (AP), Right posterior-anterior oblique (RPO), and Left posterior-anterior oblique (LPO)), were performed. Software based on the Monte Carlo program has been used to calculate the estimated absorbed dose of the organ, the risk of cancer due to exposure, and the dose received by the gonads with different projections. The results showed that the PA projection on abdominal examination resulted in lower absorbed doses for the colon wall, liver, pancreas, and small intestine wall compared to the AP projection. The AP projection resulted in a higher absorbed dose than the oblique projection on the lumbar vertebral examination. RPO and LPO projections on lumbar spine examination produce different absorbed doses in organs. The colon wall, kidneys, pancreas, and prostate in men received lower doses using LPO, and the bladder, liver, ovaries (women), small intestine wall, and uterus in women received lower doses using projected RPO. The risk of cancer due to radiation exposure on abdominal examination is 35%-51% reduced using the PA projection, and on examination of the lumbar spine 40%-45% is reduced using the LPO projection. The dose received by the gonads showed that the ovarian dose reduction was 54% using the abdominal PA projection and 11% using the lumbar RPO. The dose reduction in the testicles was shown to be significant with the use of the abdominal PA projection.

Keywords: Service system, multiphase, hospital.

1. Introduction

The use of various radiology modalities continues to grow in clinical applications in medicine. Data shows that in Indonesia, the use of radiological imaging modalities in the field of Health is quite high. As quoted from the BAPETEN website as of November 2022, there are 5,385 licenses for the use of facilities in diagnostic and interventional radiology, 20 construction and operation licenses for use in radiotherapy, and 19 construction and operation licenses for use in Nuclear Medicine (BAPETEN, Profile, 2022). This data illustrates that the use of radiation in the health sector is quite widespread. As described by Sholihah (2019), the largest contribution of radiation doses received by the world's population is from radiation applications in the medical field, and more than 90% of this contribution comes from diagnostic X-rays.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) states that the largest share of radiation applications in the health sector is from exposure to X-ray radiation in routine diagnostic radiology examinations (Gonzales, 2014). Diagnostic radiology examinations using conventional X-rays will continue to be commonly used although current developments in imaging modalities have led to modern non-ionizing imaging systems that offer reduced radiation and better image quality. The strong reason for using this conventional X-ray modality is that it is more widely available and cheaper than others (Chaparian, Kanani, & Baghbanian, 2014). Data also shows that in 2000 the number of routine diagnostic radiology X-ray examinations carried out worldwide was reported to be around 1910 million, increasing to 3100 million in 2008, and will continue to increase until now (Hiswara, 2015).

Radio diagnostic examination is one of the uses of ionizing radiation to confirm the diagnosis results needed by patients to identify abnormalities in their bodies (Abraham & Huda, 2015). This examination is carried out by providing as little radiation exposure as possible, but can still provide good-quality medical imaging. Even though radiation administration is kept to a minimum, diagnostic radiology examinations still involve potential risks, such as carcinogenic effects and genetic effects (Valentine, 2007) (BEIR, 2006). Epidemiological studies have also linked the use of diagnostic X-rays with an increase in cancer in patients since 1956 (Linet & Kim, 2009). Although the individual risk of developing radiation-associated cancer from any medical imaging procedure is minuscule, the collective effective dose increases substantially from 2.3 million man-Sv to 4 million man-Sv, and the per capita dose of 0.4 mSv rises to 0.76 mSv in 2000 to 2006 shows a very significant increase in value in a short period (Linet, et al., 2012).

To obtain an image that is suitable for the examination, there are various kinds of projections that are commonly used in diagnostic radiology examinations, including the Anterior-Posterior (AP), Posterior-Anterior (PA), Lateral, and Oblique projections. Selection of the proper use of the projection can help reduce the patient's dose acceptance. Several studies have shown that the use of an anterior-posterior (PA) projection compared to an anterior-posterior (AP) projection can reduce patient doses in scoliosis radiological examinations (Ben-Sholomo, Bartal, Shabat, & Mosseri, 2013), abdomen (Ghearr & Brennan, 1998), pelvis (Weatherburn, 1983), clavicle (Entee & Kinsella, 2010), and lumbar spine (Brennan & Madigan, 2000).

The purpose of this study was to calculate and compare the estimated organ absorption dose received, the risk of cancer due to exposure to X-ray radiation with different projections on abdominal and lumbar examinations, as well as the dose received by the gonads for women and men in different projection examinations. So it is hoped that the right of the projection examination can be known to enforce radiation protection, especially in terms of reducing the absorbed dose of organs and the risk of cancer.

2. Literature Review

Radiation is the emission and propagation of energy radiated from matter (atoms) in the form of electromagnetic waves or particles. Based on the ability to ionize, radiation is distinguished from ionizing radiation and non-ionizing radiation. One form of ionizing radiation is X-rays.

The discovery of X-rays stems from the discovery of Rontgen (1845-1923), a physicist at the University of Wurzburg while working with a cathode-ray tube in 1895. Rontgen discovered that the light from the tube could penetrate an opaque material and activate a fluorescent screen or photographic film. This light comes from the emission of photons resulting from the interaction of electrons with atomic nuclei at the anode in the X-ray generator system (Adnyana, 2014). X-rays have a wavelength in the range of $10{-}11 - 10{-}8\ nm$, and have the property of being able to penetrate the material or materials in their path through interactions in the form of classical scattering, photoelectric absorption, Compton scattering, pair formation, and photonuclear disintegration, by involving a certain energy.

Radiation from X-rays has been widely applied in various fields to improve human life, one of which is in the health sector (radio diagnostics). When a radio diagnostic examination is performed, the machine will send short waves of X- ray radiation to scan the internal organs of the body. The radiation absorbed by each part of the body can vary, depending on the density of the parts/organs in it. Most X-ray particles cannot penetrate metal or solid body parts, such as bone. Bone absorbs more X-rays than muscle or flesh, so bones appear white on an x-ray photo. Likewise, diseased organ structures will usually absorb more X-rays than other body structures such as normal flesh and bones, so they will form a whiter color than other areas of body structures (Adnyana, 2014).

The amount and level of radiation exposure used in x-ray examinations are very small, so it is relatively safe for adults. However, too often undergoing examinations that use X-rays has the potential to damage the DNA in the body's cells. This can increase the risk of developing cancer later in life, even though the increased risk is relatively low. The risk of developing cancer is known to be higher in some patients with certain conditions, namely: Patients who often perform medical imaging with high doses of radiation, Patients who are children or young, Patients who are female, and Patients with certain genetic conditions that make cancer cells Body cells are more susceptible to damage when exposed to radiation. Not only that but x-ray examinations are also known to have side effects on pregnant women, especially if X-ray examinations are carried out on parts of the body that are close to the uterus and fetus (Agustin, 2022).

X-ray radiation must be monitored in its use because it relates to the safety of users, patients, staff, and the public. The interaction of ionizing radiation with the human body will result in health effects that begin with events that occur at the molecular level until they develop into clinical symptoms with the nature, the severity of symptoms, and time of appearance depending on the amount of radiation dose absorbed and the rate of reception (Hiswara, 2015). Among the harmful effects caused by radiation exposure are deterministic effects and stochastic effects. The deterministic effect occurs due to cell death as a result of whole or local radiation exposure. This effect occurs when the radiation dose received by the body exceeds the threshold dose value. This effect also occurs in individuals who are exposed shortly after the exposure occurs, and the severity will increase if the dose received is also greater.

Unlike the deterministic effect, the stochastic effect does not recognize a threshold dose. No matter how low the radiation dose received, there is always an opportunity for changes to occur in biological systems, both at the molecular and cellular levels. In this case, what happens is not cell death but changes in cells with different functions. If the cells that change are somatic cells, then these cells in the long term and coupled with the influence of other toxic substances will have the potential to grow and develop into cancer. Meanwhile, if the cells that change are genetic cells, then the properties of these modified cells can be passed on to their offspring resulting in genetic effects or inherited effects. In addition to not having a threshold dose, stochastic effects appear after a long latency period, and their severity does not depend on the incoming radiation dose, although the chance of occurrence is greater at higher doses.

The use of X-ray radiation is governed by the principle of radiation protection which consists of justification, optimization, and dose limitation (BAPETEN, Peraturan Kepala Badan Pengawas Tenaga Nuklir tentang Keselamatan Radiasi dalam Produksi Pesawat Sinar X Radiologi Diagnostik dan Intervensional, 2014). The justification principle emphasizes the use of radiation must be based on the consideration that the benefits obtained far outweigh the risks of harm. The principle of optimization emphasizes the individual dose size, the number of people exposed, and the probability of exposure is kept as low as possible (ALARA, as low as reasonably achievable). And the principle of dose limitation emphasizes the application of the largest permissible dose value that can be received by radiation workers and members of the public within a certain period without causing significant genetic and somatic effects.

3. Materials and Methods

3.1. The studied X-ray examinations

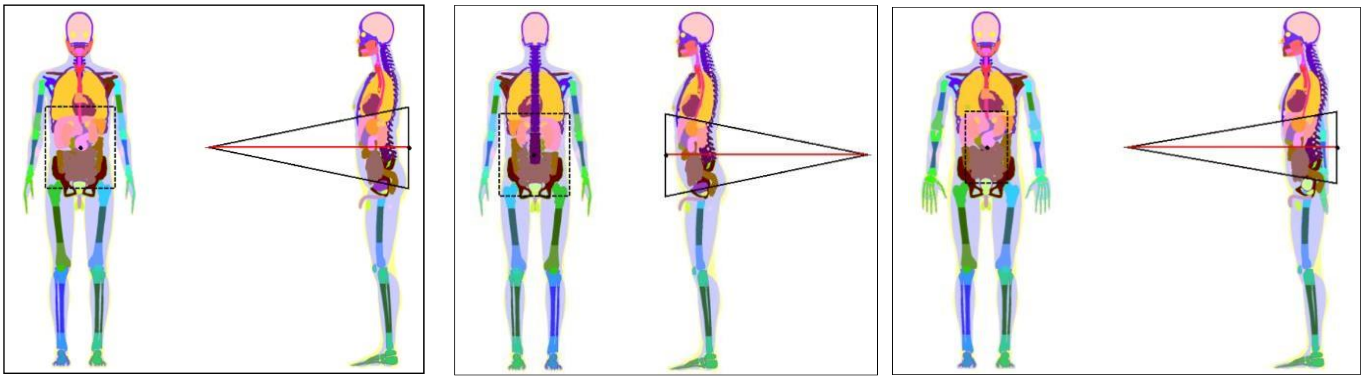
The radiographic examinations investigated included: abdominal examination (with anterior-posterior (AP) and posterior-anterior (PA) projections), and lumbar spine examination (with anterior-posterior (AP), Right posterior-anterior Oblique (RPO) and Left posterior-anterior Oblique (LPO) projections.

3.2. Patients and exposure factors

X-ray examination in this study involved patients aged 25-40 years and had a standard height of 176 cm and weight of 73 kg for men, and 163 cm and 60 kg for women. The exposure factors [X-ray tube voltage (kVp), tube current (mA), exposure time (s), SID, radiation field size] are related to each projection as shown in Table 1. The determination of this exposure factor refers to the inspection technique available by Bontrager & Lampignano (2010).

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

Examination	Projection	kVp	mAs	Source to Image Distance (SID) (cm)	Radiation field size(cm^2)
Abdomen	AP	70-80	15 - 30	100	35 x 40
	PA	70-80	15 - 30	100	35 x 40
Lumbar spine	AP	75-80	15 - 25	100	20 x 35
	RPO	60-80	15 - 25	100	20 x 35
	LPO	60-80	15 - 25	100	20 x 35



(a) (b) (c)

Figure 1: Projection examination: (a) AP abdomen, (b) PA abdomen, (c) AP Lumbar

3.3. Calculation of absorbed dose and risk of exposure‐induced cancer death

For the calculation of absorbed dose and received cancer risk associated with different projections, an analytical simulation study was carried out. To achieve this goal, the Caldose_X software (version 5.0) based on the Monte Carlo program was used which was developed by a Brazilian scientist, Richard Kramer, et al in 2008. This software makes it possible to calculate incident dose air kerma (INAK) and entrance surface air kerma (ESAK) (two important physical quantities in X-ray diagnostics) based on the output parameters of the X-ray tube used using the Monte Carlo method.

The Monte Carlo (MC) method models all microscopic processes by following the trajectory of each X-ray particle that interacts with the material in its path. Every physical interaction of particles and materials will be calculated by the sampling method of a probabilistic distribution function, so many studies show that Monte Carlo is the most accurate method for calculating dose distribution, especially in inhomogeneous networks when the particle transport effect cannot be calculated precisely by the method. conventionally uses a deterministic algorithm (Yani, 2020).

Caldose_X software uses conversion coefficients in determining absorbed doses and effective doses of organs and tissues of the human body, as well as in determining how much the risk of cancer incidence and the risk of death from cancer are as a result of irradiation or exposure to radio diagnostic exposure (Kramer, 2008). The conversion coefficient is the ratio of the results of calculations and measurements of absorbed doses of human organs using phantom FAX06 and MAX06 which refers to ICRP89 (Kramer, 2008).

In this study, the organ absorption doses studied were the bladder, colon wall, kidney, liver, pancreas, small intestine wall, ovaries, and uterus for women, and testes and prostate for men.

4. Results and Discussion

4.1. Result

Table 2 shows a comparison of the absorbed dose from the organs or tissues which is significantly different for each projection associated with the different X-ray examination projections. The bladder, colon wall, kidney, liver, ovaries (women), testicles (men), pancreas, small intestine wall, uterus (women), and prostate (men), are the organs and tissues exposed to this X-ray examination.

Table 2: The Comparisons of absorbed doses (mGy) of the different organs or tissues for each projection related to the different Xray examination

Examination	Projection		Doses absorbed in organs									
			Bladder	Collon wall	Kidneys	Liver	Ovaries (women)	Testicles (men)	Pancreas	Small intestine wall	Uterus (women)	Prostate (men)
Abdomen	AP	mean dose	0.1994	1.5104	0.4706	1.6568	0.6652	0.0168	1.3397	1.2587	0.4476	0.059
		± SD	0.062978	0.46304	0.152602	0.508518	0.217964	0.01006	0.419714	0.394834	0.151178	0.019748
	PA	mean dose	0.2678	0.5275	1.6422	0.485	0.3036	0	0.5181	0.3446	0.483	0.1232
		± SD	0.088077	0.179648	0.662409	0.230086	0.103321	0	0.198978	0.11991	0.169638	0.043136
	dose reduction* (%)		-34.3029	65.07548	-248.959	70.7267	54.35959	100	61.32716	72.62255	-7.90885	-108.814
Lumbar Spine	AP	mean dose	0.1255	0.8364	0.2478	0.8956	0.3954	0.0066	1.0659	1.1016	0.2662	0.0278
		± SD	0.024089	0.117257	0.029465	0.10542	0.044123	0.001817	0.176136	0.15342	0.028874	0.001483
	RPO	mean dose	0.0344	1.268	0.317	0.0426	0.093	0	0.3748	0.3318	0.0446	0.01125
		± SD	0.010362	0.137425	0.112333	0.00998	0.017564	0	0.097719	0.151632	0.011718	0.005058
	LPO	mean dose	0.0362	0.6296	0.223	0.8921	0.1034	0	0.1038	0.3345	0.0498	0.011
		± SD	0.011764	0.067408	0.071825	0.11275	0.022744	0	0.034045	0.145451	0.013027	0.004082
	dose reduction* (%)		-5.23256	50.347	29.653	-1994.13	-11.1828	0	72.30523	-0.81374	-11.6592	2.222222

*Negative values indicate an increased absorbed dose of that organ or tissue in the second projection compared with the first projection. AP: Anteroposterior; LPO: Left posterior‐anterior oblique, PA: Posteroanterior, RPO: Right posterior‐anterior oblique, SD: Standard deviation

Table 3 also illustrates the comparison of cancer risk in different X-ray examinations for male and female patients. The different estimates of cancer risk are largely based on the dose absorbed by the various organs or tissues exposed to the examination, some of which are presented in Table 2.

A comparison of mean Entrance Surface Dose (ESD) values and Risk of death from cancer resulting from radiation exposure for the use of similar projections is given in Table 4. These values were taken from abdominal and lumbar examinations using paired projections that can display similar anatomy and organs but in opposite directions. The value of the risk of death from cancer listed in Table 4 is the sum of the risks of various types of cancer due to radiation exposure received by various organs or tissues shown in Table 2, and other organs that are not mentioned. The word "average" refers to the value obtained for all patients with the use of certain exposure factors in this study. In other words, the risk of cancer due to radiation exposure and the risk of final death associated with each projection is calculated separately for each patient with a certain exposure factor and then the average values obtained are shown in this table.

More specifically, the mean values of gonadal absorbed dose for each projection associated with different X-ray examinations are given in Table 5. The ovarian absorbed dose data for women and testicular absorbed dose for men can be used to select the appropriate projection from certain types of examinations so that genetic effects can be minimized.

4.2. Discussion

The data from this study indicate that the use of proper positioning during X-ray examination of the abdomen and lumbar spine reduces the stochastic hazard to patients from ionizing radiation. In this study, in addition to estimated organ absorbed dose, cancer risk scores, and estimated risk of death from cancer resulting from radiation exposure using different projections were calculated for men and women. The gonadal absorbed dose was also calculated for comparison of the hereditary effects of radiation in the various radiographic projections mentioned as given in the Table 3.

Table 3: The comparisons of risk of cancer for patient male and female in the different X-ray examinations (per million cases)

Examination	Projection		male		female	
			risk of cancer incidence	risk of death from cancer	risk of cancer incidence	risk of death from cancer
Abdomen	AP	mean dose	0.3279	0.18338	0.53098	0.25646
		± SD	0.105901	0.059626	0.184239	0.0882
	PA	mean dose	0.21188	0.1315	0.2606	0.16316
		± SD	0.072583	0.044989	0.079106	0.050501
	dose reduction (%)		35.38274	28.29098	50.92094	36.37994
Lumbar Spine	AP	mean dose	0.1847	0.10108	0.22158	0.1151
		± SD	0.01916	0.010363	0.044656	0.021586
	RPO	mean dose	0.19292	0.09886	0.18438	0.09382
		± SD	0.028299	0.014807	0.02299	0.011734
	LPO	mean dose	0.11586	0.20228	0.10076	0.05662
		± SD	0.018435	0.31634	0.007734	0.004884
	dose reduction (%)		39.94402	-104.613	45.35199	39.65039

*Negative values indicate an increased absorbed dose of that organ or tissue in the second projection compared with the first projection. AP: Anteroposterior; LPO: Left posterior‑anterior oblique, PA: Posteroanterior, RPO: Right posterior‑anterior oblique, SD: Standard deviation.

Table 4: The mean value of Entrance Surface Dose (ESD) and risk of exposure-induced cancer death for similar projection X-ray examination

Examination	Projection	ESD (mGy)	± SD	the mean value of the risk of exposure-induced cancer death (per million)					
				male	±SD	risk reduction (%)	female	±SD	risk reductio n(%)
Abdomen	AP	5.455	1.567959	0.18338	0.059626	28.29098	0.25646	0.0882	36.37994
	PA	5.501	1.576074	0.1315	0.044989		0.16316	0.050501	
Lumbar Spine	RPO	1.433	1.055652	0.09886	0.014807	-104.613	0.09382	0.011734	39.65039
	LPO	1.427	1.047527	0.20228	0.31634		0.05662	0.004884	

*Negative values indicate an increased absorbed dose of that organ or tissue in the second projection compared with the first projection. AP: Anteroposterior; LPO: Left posterior‑anterior oblique, PA: Posteroanterior, RPO: Right posterior‑anterior oblique, SD: Standard deviation as Table 5.

Table 5: The mean value of gonad absorbed doses for each projection related to the different X-ray examination

Examination	Projection	the mean doses to the gonads (mGy)					
		Ovaries	± SD	dose reduction from similar projection (%)	Testicles	±SD	dose reduction from similar projection (%)
Abdomen	AP	0.6652	0.217964	54.35959	0.0168	0.01006	100

	PA	0.3036	0.103321		0	0	
Lumbar Spine	AP	0.3954	0.044123		0.0066	0.001817	
	RPO	0.093	0.017564	-11.1828	0	0	0
	LPO	0.1034	0.022744		0	0	

*Negative values indicate an increased absorbed dose of that organ or tissue in the second projection compared with the first projection. AP: Anteroposterior; LPO: Left posterior‑anterior oblique, PA: Posteroanterior, RPO: Right posterior‑anterior oblique, SD: Standard deviation

According to the results of this study, a significant reduction in absorbed radiation dose and reduction in radiation risk was observed more in the PA position than in the AP position for abdominal radiographs. This is proven by data showing that PA projection causes 54% – 100% of the absorbed dose for organs of the colon wall, liver, ovaries (women), testicles (men), pancreas, and small intestine wall lower than AP projection, reducing the risk of cancer incidence for men and women respectively 35.38% and 50.92%, and the reduction in the risk of death from cancer resulting from radiation exposure for men and women respectively 28.29% and 36.38%. Except for the bladder, kidney, uterus (women), and prostate (men), all four of them experienced an increased radiation dose. These results are in agreement with previous studies, where PA projections significantly reduced the effective dose for abdominal examinations (Chaparian, 2014), (Brennan & Madigan, 2000), (Ghearr & Brennan, 1998).

A comparison of projections on lumbar spine examination also shows that the AP projection produces a higher absorbed dose than the oblique projection (RPO and LPO). Further analysis showed that projected LPO compared to RPO caused the absorbed dose to the colon wall, kidney, pancreas, and prostate organs in men to decrease by 50.35%, 29.65%, 72.30%, and 2.22% respectively. Meanwhile, the bladder, liver, ovaries (women), small intestine wall, and uterus (women) organs have increased. As for the overall risk of cancer incidence received from lumbar vertebral examination, the use of the LPO projection is lower than the RPO projection, namely 39.9% for men, and 45.35% for women.

Examination of the lumbar vertebrae using oblique projections actually can use a comparison of paired projections between RAO and LPO, and LAO and RPO. The pair of projections will be better able to show anatomy and organs that are very similar but in opposite directions. But in this Caldose_X software, the projections that can be used are LPO and RPO. This is according to the default settings contained in the program. The reference indicates that in X-ray examination of the lumbar spine that the LAO projection leads to 53% lower effective dose than the RPO projection, and 56% and 63% radiation reduction for males and females respectively. And RAO projections lead to 28% lower effective dose than LPO projections, and 52% and 39% radiation risk reduction for men and women respectively (Chaparian, 2014).

In general, for all radiographic projections, the risk of radiation-induced carcinogenesis is lower the more sensitive organs are located in the X-ray tube. Also, another reason for this reduction is that these organs are protected by other structures such as the pelvic bones and the lumbar spine. The evaluation results presented in Table 2 confirm this fact. For example, the negative values of reduced dose for the bladder in Table 2 indicate an increased dose absorbed by that tissue in the PA projection compared to the AP projection, because the bladder is located closer to the X-ray tube in the PA projection than in the AP projection unlike other organs such as the intestine large, liver, and pancreas. However, the highest organ dose does not necessarily lead to the highest risk of exposure-induced cancer associated with that organ, because exposure-induced cancer risk is estimated based on organ sensitivity, cancer location, sex, and age at exposure, in addition to organ dose (Chaparian, 2014).

In Table 5, the doses received by the gonads in various positions of the abdomen and lumbar spine are shown separately for men and women. The dose received by the gonads can be used to estimate the hereditary risk arising from radiation for men and women of reproductive age (ICRP, 2013). Use of the PA position rather than the AP can result in a female ovarian dose reduction on abdominal radiographs by 54.36%, and a male testicle dose reduction by almost 100%. On lumbar vertebral examination, an additional dose to ovaries (Women) occurred in the LPO projection. And there was no observed value of the absorbed dose of the testes (men) which was measured on the oblique projection examination.

It is important to note that the suggested position may introduce certain limitations such as reduced image quality and patient comfort in acute injuries. However, several evaluations performed on previous studies [4] (Chaparian, 2014) (Brennan & Madigan, 2000), (Ghearr & Brennan, 1998) showed no significant reduction in image quality between similar projections such as AP and PA. There was no difference in patient comfort, in the oblique projection of the lumbar spine, the patient had to be stabilized in all four projections and there was no significant difference in patient comfort in any of the projections. Therefore by applying the chosen projections, the benefits of reducing the radiation risk always outweigh any possible limitations.

5. Conclussion

The results of this study indicate a better type of projection for reduced organ-absorbed dose, radiation-induced cancer risk, and gonadal dose. The recommended projection, whenever possible, for abdominal X-ray examination, is the PA rather than the AP projection. Also, the projections suggested for radiographs of the lumbar spine better take into account the needs of the examination taking into account the level of sensitivity and organ location, sex, and age at exposure. Even though research shows the amount and level of radiation exposure used in x-ray examinations is very small, diagnostic radiology examinations still involve potential risks, such as carcinogenic effects and genetic effects, so the principle of radiation protection must be enforced.

From this study, it is felt that further research is needed to review the estimated organ absorption dose, the risk of cancer due to radiation exposure, and the risk of death by carrying out examinations using projection pairs between AP and PA, LPO and RAO, RPO and LAO, LLAT and RLAT.

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