EFFECT OF DIFFERENT PHANTOM POSITIONS IN LATERAL LUMBAR SPINE RADIOGRAPHY ON EFFECTIVE DOSE AND ABSORBED DOSE TO SELECTED ORGANS

by

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This study aimed to investigate the different positioning of the patient in left and right lateral position during lumbar spine radiography and its effects on effective dose and absorbed dose for selected organs. The study was performed on a Siemens Multix/Vertix X-ray unit using Agfa's computer radiography system. Two anthropomorphic phantoms (PBU 60 and RS 113T) were imaged in both lateral projections with a tube voltage from 79 kV to 90 kV. The dose was measured with a DAP meter placed under the collimator of the X-ray unit. The effective dose and absorbed dose for selected organs were calculated using the Monte Carlo simulation programme PCXMC 2.0. Based on Monte Carlo simulation calculations, the results of effective dose on a PBU 60 phantom showed a decrease of 15.2 %, while the decrease in effective dose on a RS 113T phantom was 14.2 % in favour of the right lateral projection. An absorbed organ dose to selected organs showed a significant dose reduction for lymph nodes, pancreas, small intestine, spleen, and stomach in favour of this projection. Based on the results, we can conclude that right lateral projection should be the method of choice when imaging the lumbar spine in the lateral projection.

Key words: lumbar spine radiography, radiation dose reduction, radiosensitive organ

INTRODUCTION

Lumbar spine radiography is one of the seven most commonly performed imaging in general radiography. In addition to the lumbar spine, the most common procedures are chest radiography, cervical spine, thoracic spine, pelvis and hip radiography, abdominal radiography, and mammographic imaging [1]. When inspecting the dose, lumbar spine radiography provides the highest radiation dose to the patient, especially in the lateral position [2-6]. The most common value of the dose area product (DAP) of lumbar spine radiography, based on the results of research in 36 European countries, is 420 μGy m^2. The range of DAP is from 275 to 800 μGy m^2 [7]. According to ICRP document No. 103, the most radiosensitive organs are breasts, bone marrow, colon, stomach, and lungs [8]. In lumbar spine radiography, some of the mentioned radiosensitive organs are located in the primary fields or close to the primary field. Therefore, it is crucial to keep the radiation dose to the patient as low as reasonably achievable [9]. Dose reduction in general radiography can be achieved by various approaches, such as the use of alternative exposure parameters, additional filtration, use of proper collimation, and different patient positioning [9-11].

Since the position of the patient during imaging of the lumbar spine in lateral position usually depends on the orientation of the X-ray unit and the preferences of the radiographer [12], we decided to investigate whether the different positioning of the patient on the left lateral and right lateral side (LLAT and RLAT) results in a different effective dose and absorbed dose for selected organs.

MATERIALS AND METHODS

A prospective study was performed using an experimental method to investigate the effect of different positioning in lateral lumbar spine radiography. The study was conducted on a Siemens Multix/Vertix X-ray unit with a total beam filtration of 2.5 mm Al (Siemens AG, Germany). Prior to the study, quality control tests were performed. The performed tests were related to the reproducibility of the radiation output, the accuracy of nuclear voltage assessment of the

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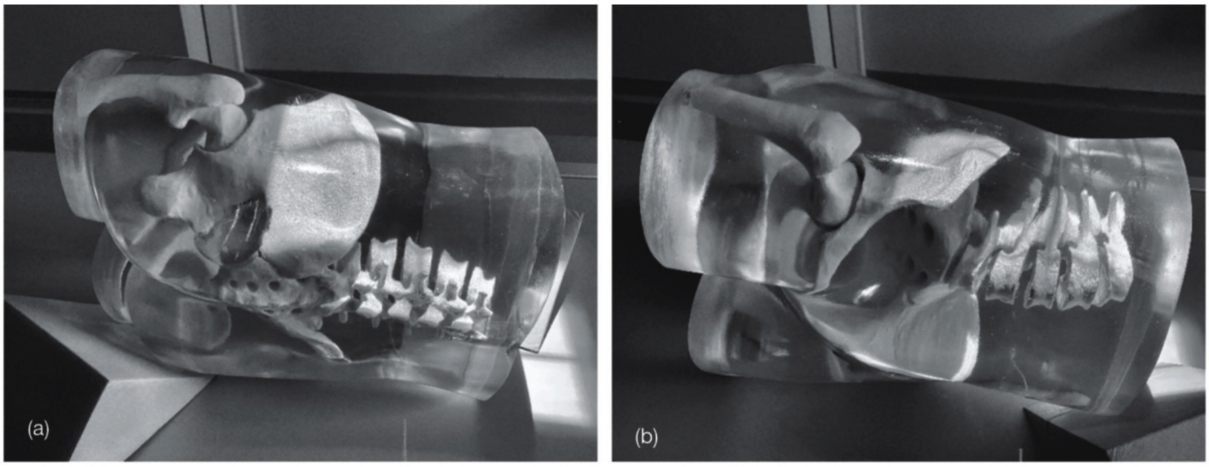

Figure 1. Positioning of the phantom RS 113T in LLAT (a) and RLAT (b)

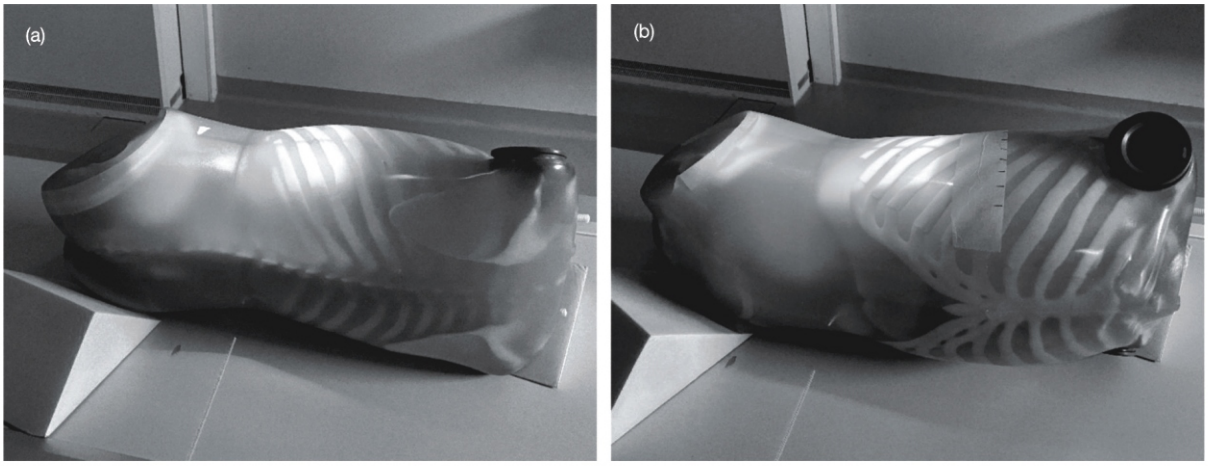

Figure 2. Positioning of the phantom PBU 60 in LLAT (a) and RLAT (b)

half-value layer, the AEC device, and the test of DAP accuracy. All tests showed that the unit is working within the expected tolerances [13]. Imaging was performed on two different anthropomorphic phantoms. The first phantom represents a patient with a height of 175 cm and a weight of 74 kg (RS 113T; Radiology support devices, 2020), fig. 1, and the second phantom represents a patient with a height of 165 cm and a weight of 50 kg (PBU 60; Koyoto Kagaku, 2020), fig. 2. Imaging was performed with a computer radiography (CR) system, using 35 cm × 43 cm image receptors from Agfa (Agfa – Gevaert N.V., Belgium).

The exposure parameters used in our study were based on the European recommendations for computer radiography and digital radiography systems, which state that the range of lumbar spine radiography in the lateral position is between 80 kV and 90 kV [14]. Both anthropomorphic phantoms were imaged with a tube voltage from 79 kV to 90 kV, using a central chamber of automatic exposure control (AEC), a large focal spot of 1.0 mm, and a source-to-image receptors distance (SID) of 115 cm. Both phantoms were positioned following patient positioning recommendations for lateral lumbar spine radiography [9, 12]. The central beam was placed four centimetres above the iliac crest [12]. The image field size with the phantom PBU 60 was 31 cm × 16.5 cm and with the phantom RS 113T was 37 cm × 17.5 cm Both mentioned imaged fields were determined based on the anthropomorphic phantom anatomy so that all diagnostically important structures were shown on the image, the entire lumbar spine, the last thoracic vertebra (Th 12), and the first sacral vertebra (S1) [9, 12]. The DAP values were measured with the Diamentor M4-KDK, T11017-0044 DAP meter (PTW Freiburg, Germany), which was placed under the collimator of the X-ray unit. Each phantom was imaged five times under the same tube voltage conditions and same lateral position (LLAT or RLAT). Between each exposure, the phantom was removed from the examination table and repositioned so that positioning error was also included in the measurements. In the projection, the first letter L for left and R for right describes the entry side of the primary beam.

In this study, image quality was not assessed because we used exposure parameters based on European guidelines [14] and a change in positioning should not affect image quality. After all, the professional literature describes that both projections are possible [12].

The effective dose and the dose to selected organs were calculated using the Monte Carlo simulation software PCXMC 2.0 (STUK, Radiation Protection and Nuclear Safety Authority of Finland). The weight, height, image field size value, total filtration, tube voltage, and imaging projection were entered into the program separately for each phantom. The number of photon particles was one million to ensure a low calculation error. After the simulations, a depth value and the exact tube voltage were entered to calculate the effective dose and the absorbed dose for the organs. The absorbed dose is presented with the selected organs located in the primary field or close to the primary field. These organs are adrenal glands, colon, gall bladder, kidneys, liver, lungs, lymph nodes, pancreas, small intestine, spleen, stomach, and uterus.

Data were analysed using IBM SPSS statistics version 26 (IBM, USA). A Shapiro-Wilk test was used to determine the normal distribution of the sample. Since the data were not normally distributed, a nonparametric Mann-Whitney *U* test was performed. A significance of $p < 0.05$ was used for all tests. The results are presented in the form of tables and boxplot diagrams.

RESULTS

One hundred and twenty exposures were made (60 exposures on a PBU 60 phantom and 60 on a RS 113T phantom). There were no statistically significant differences ($p = 1.000$) in DAP values between LLAT and RLAT on both phantoms. Descriptive statistics for effective dose on the PBU 60 phantom are shown in tab. 1 and for the RS 113 T phantom in tab. 2.

The results show that with RLAT, the effective dose decreases by 15.2% compared to LLAT on a phantom PBU 60. Statistical comparison was performed using a Mann-Whitney *U* showing a statistically significant difference ($p < 0.001$) in the effective dose between LLAT and RLAT on the previously described phantom. The results are also shown in the boxplot diagrams in fig. 3.

Table 1. Descriptive statistics value for effective dose on a phantom PBU 60

Projection	Mean [μSv]	Std. dev. [μSv]	Median [μSv]	Minimum [μSv]	Maximum [μSv]
LLAT	192.3	14.1	188.3	171.5	223.1
RLAT	163.2	12.2	159.7	145.1	189.7

Table 2. Descriptive statistics value for effective dose on a phantom RS 113T

Projection	Mean [μSv]	Std. dev. [μSv]	Median [μSv]	Minimum [μSv]	Maximum [μSv]
LLAT	158.4	11.9	158.5	140.0	181.8
RLAT	135.9	10.6	135.9	119.5	156.5

On the phantom RS 113 T, the decrease in effective dose in the RLAT position was 14.2 % compared to the LLAT position. A Mann-Whitney U test was performed which showed a statistically significant difference ($p < 0.001$) between the LLAT and RLAT positions of the phantom. The results are shown graphically in fig. 4.

Since we have proved statistically significant differences in effective dose at both phantoms, the absorbed dose at selected organs is also presented to show which of the organs influence the difference in effective dose. The comparison of absorbed organ doses in LLAT and RLAT is presented in tab. 3 for a PBU 60 phantom and in tab. 4 for a RS 113 T phantom.

Based on the results from tab. 3, we can see that there are no statistically significant differences in absorbed organ dose between LLAT and RLAT on active bone marrow, adrenals, kidneys, and uterus. A Mann-Whitney U test showed statistically significant differences between lymph nodes (22.8 %), ovaries (3.9 %), pancreas (80.2 %), small intestine (4.8 %), spleen (97.7 %), and stomach (89 %) in favour of the RLAT position. Based on the Mann-Whitney U test, a statistically significant difference was found in the colon (9.6 %), gallbladder (70 %), liver (95.9 %), and lungs (12.0 %) in favour of LLAT position using PBU 60 phantom. The results are also shown graphically in fig. 5.

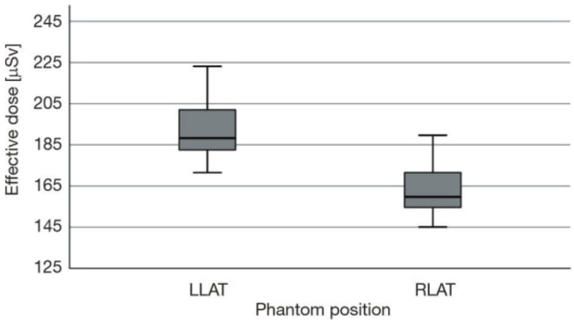

Figure 3. Comparison of effective those between LLAT and RLAT positions of the PBU 60 phantom

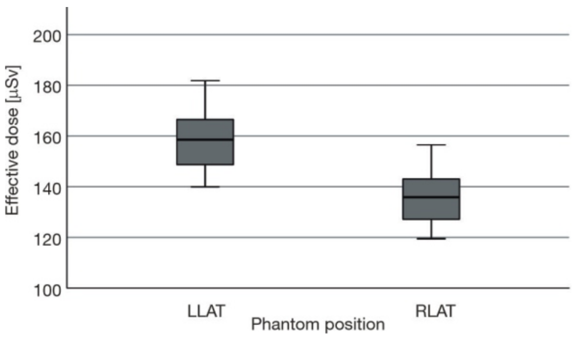

Figure 4. Comparison of effective those between LLAT and RLAT positions of the RS 113T phantom

Table 3. Descriptive statistic values for absorbed organ dose in the phantom PBU 60

Organ	Projection	Mean [Gy]	Median [Gy]	Std. dev. [Gy]	Min [Gy]	Max [Gy]	*p*-value
Active bone marrow	LLAT	190.7	186.8	12.9	171.7	219.5	$p = 0.734$
	RLAT	190.3	186.4	12.8	171.4	218.9	
Adrenals	LLAT	226.2	226.5	13.9	205.7	257.9	$p = 0.114$
	RLAT	230.6	226.8	14.1	209.8	262.5	
Colon	LLAT	324.5	317.6	22.7	291.1	374.7	$p < 0.001$
	RLAT	358.9	351.1	25.6	321	415.1	
Gallbladder	LLAT	151.5	149.5	6.7	141.9	168	$p < 0.001$
	RLAT	504	494.2	33.2	454.6	578	
Kidneys	LLAT	858.6	843.1	70.1	755.4	1008.4	$p = 0.712$
	RLAT	862.8	846.9	70.7	758.6	1013.1	
Liver	LLAT	47.1	46.6	1.6	44.5	51.3	$p < 0.001$
	RLAT	1149	1126.1	112.5	984.1	1380	
Lungs	LLAT	22.1	21.7	1.1	20.5	24.7	$p < 0.001$
	RLAT	25.1	24.6	1.3	23.1	28.1	
Lymph nodes	LLAT	267.6	261.9	18.9	239.8	309.2	$p < 0.001$
	RLAT	206.7	202.9	13.3	187	236.5	
Ovaries	LLAT	241.5	237.5	14.1	220.8	274	$p = 0.003$
	RLAT	232.1	228	13	213	262	
Pancreas	LLAT	964.3	680.8	53.6	615.4	810.2	$p < 0.001$
	RLAT	190.6	187.5	9.5	176.8	213.2	
Small intestine	LLAT	471.4	462.2	31.4	425.1	541.5	$p = 0.003$
	RLAT	449	440.2	29.7	405.1	515.2	
Spleen	LLAT	1981.7	1943.9	187	1707.7	2396.3	$p < 0.001$
	RLAT	45.6	45.4	1.3	42.7	48.9	
Stomach	LLAT	525.5	515.2	40.2	466.1	612.6	$p < 0.001$
	RLAT	58	57.2	2.1	54.9	63.3	
Uterus	LLAT	121.2	119.6	5.4	113.4	134.5	$p = 0.487$
	RLAT	121.6	120.0	5.4	113.8	134.9	

In tab. 4, we can see that there are no statistically significant differences in absorbed organ dose between LLAT and RLAT on bone marrow, adrenals, colon, kidneys, ovaries, and uterus. Using the Mann-Whitney U test, we found statistically significant differences in the lymph nodes (30.9 %), pancreas (80.9 %), small intestine (4.9 %), spleen (98.8 %), and stomach (91.8 %) in favour of the RLAT position. Statistically, significant differences based on the Mann-Whitney U test were found for gallbladder (74.8 %), liver (97.3 %), and lungs (14.6%) in favour of the LLAT position using the phantom RS 113T. The results are also shown graphically in fig. 6.

DISCUSSION

This study aimed to investigate whether different patient positions (LLAT and RLAT) and lateral projection provide a difference in the effective dose and absorbed dose for selected organs during imaging of the lumbar spine. When comparing the DAP values between different lateral projections of the lumbar spine, we found that there were no statistically significant differences between them. Such a result was expected since we only changed the position of the phantom from one side to the other.

When comparing the effective dose on the PBU 60 phantom, we found that the dose decreased by 15.5 % (29.1 μSv) when the RLAT projection was chosen. Similar results were found on the phantom RS 113 T in the RLAT position, which was 14.2 % (22.5 μSv) lower compared to the LLAT position of the phantom. When we compare the absolute values of the effective dose between the two phantoms, we can see that the effective dose in both projections is much higher on the PBU 60 phantom, which represents a smaller patient than on the RS 113T phantom, which represents a standard patient (175 cm and 74 kg). This is due to the absorption of the higher energy photons in a larger phantom (RS 113 T). The results of our study are consistent with the results of the simulation study by Ben-Shlomo *et al*. [15], where they have found a mean difference of 26.9 % in the effective dose between LLAT and RLAT in lumbar spine radiography. The difference between LLAT and RLAT projections is about 10 % greater in their study, which could be due to different exposure parameters. The absolute values of effective dose in their study are 163 μSv in RLAT position and 223 μSv in LLAT position. They describe that their study is a simulation study using the Monte Carlo simulation program PCXMC 2.0 and not a study based on phantom or patient measurements. A study similar to our study was conducted by Chaparian *et al*. [16] where they have measured entrance skin dose in

Table 4. Descriptive statistic values for absorbed organ dose in the phantom RS 113T

Organ	Projection	Mean [Gy]	Median [Gy]	Std. dev. [Gy]	Minimum [Gy]	Maximum [Gy]	*p*-value
Active bone marrow	LLAT	173.6	173.8	12.8	153.8	198.8	$p = 0.824$
	RLAT	173.8	173.8	12.7	153.9	199	
Adrenals	LLAT	204.5	204.8	12.8	184.3	230.3	$p = 0.615$
	RLAT	203.1	203.2	12.1	183.7	228	
Colon	LLAT	265.3	265.5	18.8	236.1	302.4	$p = 0.525$
	RLAT	262.4	262.6	18.5	233.2	299.2	
Gallbladder	LLAT	80.2	79.9	3.1	75.1	87.2	$p < 0.001$
	RLAT	318.3	318.8	20.1	286.2	359.1	
Kidneys	LLAT	633.9	633.7	54.1	551	737.8	$p = 0.701$
	RLAT	638.5	638.1	54.5	554.4	743.4	
Liver	LLAT	26.5	26.5	0.8	25.1	28.4	$p < 0.001$
	RLAT	986.1	983.9	100.6	833.5	1174.9	
Lungs	LLAT	23.4	23.4	1.3	21.3	26.1	$p < 0.001$
	RLAT	2.4	27.4	1.6	24.8	30.7	
Lymph nodes	LLAT	202.3	202.5	14.9	179.3	231.6	$p < 0.001$
	RLAT	139.7	139.8	9	125.4	157.9	
Ovaries	LLAT	301	301.3	18.3	272.2	338.2	$p = 0.976$
	RLAT	301	301.1	17.7	272.6	337.4	
Pancreas	LLAT	586.2	586.2	47.6	513.1	678.4	$p < 0.001$
	RLAT	111.9	111.6	5.1	103.5	123	
Small intestine	LLAT	325.9	326.4	21.7	292	369.4	$p = 0.008$
	RLAT	309.8	310.1	20.4	277.4	350.9	
Spleen	LLAT	1822.3	1819.8	179.6	1550.6	2160.1	$p < 0.001$
	RLAT	22.5	22.5	0.4	21.8	23.7	
Stomach	LLAT	364.8	365.1	27.9	321.6	419.4	$p < 0.001$
	RLAT	29.9	29.9	0.8	28.6	13.9	
Uterus	LLAT	140.3	140	6.3	130.2	154	$p = 0.280$
	RLAT	142.2	141.9	6.6	131.5	156.4	

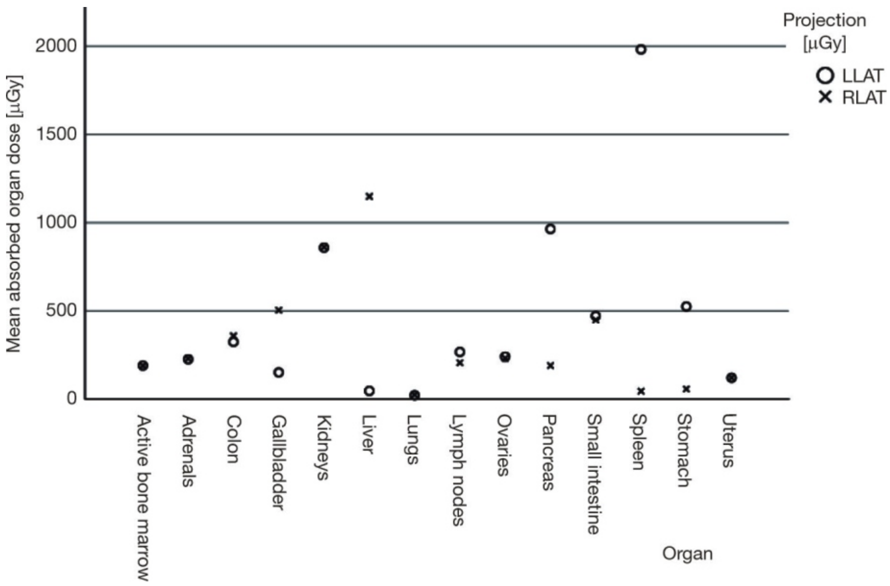

Figure 5. Comparison of mean absorbed organ those be ween the LLAT and RLAT positions of the phantom on selected organs on the phantom PBU 60

the patient study for abdomen, lumbar spine, and pelvic examinations. They reported a mean difference in effective dose between LLAT and RLAT positions of 19.2 %. The absolute values in their study are much higher, which describes a mean effective dose in the LLAT projection of 450 μSv and the RLAT of 557 μSv. There is also a difference between the LLAT and RLAT positions in their study and ours, which could be due to a different interpretation of the LLAT and RLAT positions. As described in our methodology, the letter before the lateral projection is the position where the primary beam enters the phantom's body. The difference in the absolute values of the effective dose could be due to the different exposure parameters used in their [16] and our studies.

In our study, we also compared the absorbed dose between LLAT and RLAT projections in lumbar spine

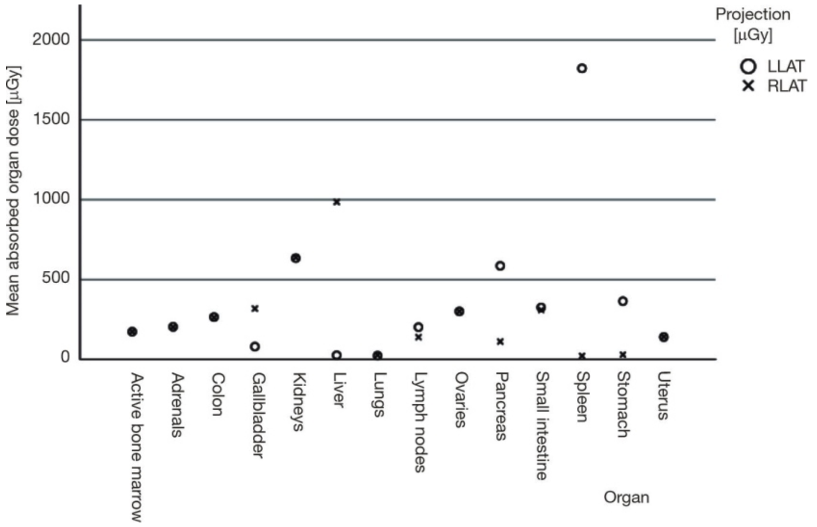

Figure 6. Comparison of mean absorbed organ dose between the LLAT and RLAT positions of the phantom on selected organs on the phantom RS 113T.

radiography. On the phantom PBU 60, the results of absorbed organ doses showed statistically significant differences between lymph nodes, ovaries, pancreas, small intestine, spleen, and stomach in favour of RLAT. In the phantom RS 113 T, there were statistically significant differences in favour of RLAT projection in lymph nodes, pancreas, small intestine, spleen, and stomach. We see that mainly the same organs receive a lower absorbed radiation dose, except for the ovaries, which is due to the priority mentioned higher energy photons in the larger phantom. When we compare these results with the results of the study by Chaparian *et al*. [16], we see a large difference in the dose to the organs. This could be due to different exposure parameters and a different size of the patients, as their study was performed on patients, while our study was performed on two different anthropomorphic phantoms.

The main limitation of our study is that the research was conducted on phantoms only and we did not include any patients in our study. Another limitation is that we used a smaller phantom (PBU 60) and a phantom representing a standard patient (RS 113 T). An additional phantom representing a larger patient would also be beneficial to our study.

CONCLUSION

In our study, we have inspected whether the different positioning of the phantom in the lateral projection during radiography of the lumbar spine results in the different effective dose and absorbed dose for selected organs. We have proven a statistically significant reduction in the effective dose of 15.2 % and 14.2 %, respectively, and a significant reduction in the absorbed dose for lymph nodes, pancreas, small intestine, spleen, and stomach in favour of the RLAT projection in the lateral lumbar spine radiography. Based on these results, we can conclude that the method of choice for lumbar spine radiography and lateral position is the RLAT position. We recommend repeating the study on patients to obtain the results in a clinical environment.

AUTHORS CONTRIBUTIONS

E. Alukic has performed the literature review, data preparation for statistical analysis, and wrote the manuscript. N. Mekiš has performed the measurements, statistical analysis, reviewed the manuscript, and prepared the manuscript based on the journal's format.

REFERENCES

[1] ***, European Union, Diagnostic Reference Levels in Thirty-six European Countries, Part 1/2, Radiation Protection N° 180, 2015
[2] ***, European Commission, European Guidelines on Quality Criteria for Diagnostic Radiographic Images, EUR 16260 EN, 1996
[3] Frank, E. D., *et al*., Use of the Posteroanterior Projection: A Method of Reducing X-Ray Exposure to Specific Radiosensitive Organs, *Radiologic Technology, 54* (1983), 5, pp. 343-347
[4] Hart, D., *et al*., HPA-CRCE-012 Frequency and Collective Dose for Medical and Dental X-Ray Examinations in the UK, 2008, 2010
[5] Long, B. W., *et al*., Radiography Essentials for Limited Practice, Elsevier: 2016
[6] Nic An Ghearr, F. A., Brennan, P. C., The PA Projection of the Abdomen: A Dose Reducing Technique, *Radiography, 4* (1998) 3, pp. 195-203
[7] ***, European Union Diagnostic Reference Levels in Thirty-six European Countries, Part 2/2, Radiation Protection N° 180, 2015
[8] ***, The 2007 Recommendations of the International Commission on Radiological Protection, Elsevier, published for the International Commission on Radiological Protection, cop. 2007: Orlando 2007
[9] Medić, M., Mekiš, N., Diagnostical Radiography Methods: Skeletal Radiography (in Slovenian), Faculty of Health Sciences, Ljubljana, 2018
[10] Resnik, A., *et al*., Pelvis Imaging: Achieving Dose Reduction with Different Patient Positions, *Nucl Technol Radiat, 34* (2019), 4, pp. 375-383
[11] Pažanin, A., *et al*., Proper Collimation Effect on Radiation Dose and Image Quality in Thoracic Spine Radiography, *Nucl Technol Radiat, 35* (2020), 2, pp. 181-188

[12] Long, B. W., *et al.*, Merrill's Atlas of Radiographic Positioning & Procedures, Elsevier: St. Louis 2019
[13] Hiles, P. A., *et al*., Recommended Standards for the Routine Performance Testing of Diagnostic X-Ray Imaging Systems; Repot 91. Institute of Physics and Engineering in Medicine: York 2005
[14] Busch, H. P., Image Quality and Dose Management For Digital Radiography, 2004
[15] Ben-Shlomo, A., *et al*., Effective Dose Reduction in Spine Radiographic Imaging by Choosing the Less Radiation-Sensitive Side of the Body, *Spine Journal, 16* (2016), 4, pp. 558-563
[16] Chaparian, A., *et al*., Reduction of Radiation Risks in Patients Undergoing Some X-Ray Examinations by Using Optimal Projections: A Monte Carlo Program-Based Mathematical Calculation, *Journal of Medical Physics, 39* (2014), 1, pp. 32-39

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УТИЦАЈ РАЗЛИЧИТИХ ПОЛОЖАЈА ФАНТОМА У БОЧНИМ РАДИОГРАФИЈАМА ЛУМБАЛНЕ КИЧМЕ НА ЕФЕКТИВНУ И АПСОРБОВАНУ ДОЗУ У ОДАБРАНИМ ОРГАНИМА

Циљ рада је да се истражи различито позиционирање пацијента у левом и десном бочном положају током радиографије лумбалног дела кичме и њихов утицај на ефективну дозу и апсорбовану дозу на одабраним органима. Истраживање је изведено на апарату Siemens Multix/Vertix X-ray користећи Агфа компјутерски радиографски систем. У обе бочне пројекције сликана су два антропоморфна фантома (PBU 60 и RS 113T) са напоном цеви од 79 kV до 90 kV. Доза је мерена ДАП метром постављеним испод колиматора рендгенске јединице. Ефективна доза и апсорбована доза одабраних органа израчунате су коришћењем Монте Карло симулационог програма PCXMC 2.0. На основи Монте Карло симулације, резултати ефективне дозе на PBU 60 фантому показали су смањење ефективне дозе за 15,2 %, док је смањење ефективне дозе на фантому RS 113T било 14,2 % у корист десног бочног положаја. Апсорбована доза на одабраним органима показала је значајно смањење дозе за лимфне чворове, панкреас, танко црево, слезину и желудац у корист истог положаја. На основу добијених резултата можемо закључити да би десни бочни положај могао бити метода избора при радиографији лумбалног дела кичме у латералној пројекцији.

Кључне речи: радиографија лумбалне кичме, смањење дозе зрачења, радиосензитивни орган