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The impact of body mass index on patient radiation dose in general radiography

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Abstract

The aim of the present study was to determine the influence of the body mass index (BMI) on the dose area product (DAP) and effective dose (ED) in overweight and obese patients. We also wanted to determine the typical dose values as well as suggest adjustments to clinical practice for overweight and obese patients. In this study we considered 597 patients referred for imaging of the chest in posteroanterior and lateral projection, the lumbar spine in anteroposterior (AP) and lateral projection, the pelvis, the knee in AP and lateral projection, and the shoulder in AP projection. For each examination, the image field size, tube voltage, mAs product, source-to-image receptor distance and values of DAP were collected. Based on their BMI, the patients were divided into three groups (normal weight, overweight and obese). At the end, PCXMC 2.0 software was used to calculate the ED. The study showed a statistically significant DAP and ED increase in overweight and obese patients by 28.9% up to 275.4% in the case of DAP and an increase in ED from 11.0% to 241.9% in all mentioned examinations except knee and shoulder imaging. Typical DAP values ranged from 2.2 to 54.8 μGym^2 for normal-weight patients, from 2.2 to 87.6 μGym^2 for overweight patients, and from 2.2 to 172.5 μGym^2 for obese patients. Spearman's correlation coefficient revealed very weak to very strong correlations when comparing BMI and DAP, as well as when comparing BMI and ED. A strong and very strong correlation was found in the case of examinations of the torso (except for the comparison of BMI and ED in the case of lateral lumbar spine projection).

1. Introduction

According to 2016 World Health Organisation (WHO) data, 39% of adults are overweight and 13% are obese [1]. Similar figures to those from WHO were obtained by the Slovenian National Institute of Public Health; the results showed that 39% of the adult population is overweight and 17% is obese [2]. Overweight or obese patients present a major challenge in diagnostic radiography due to the greater thickness of the anatomical area that needs to be imaged [3].

When imaging overweight or obese patients in general radiography, automatic exposure control (AEC) leads to higher exposure factors to achieve sufficient image quality, resulting in a higher radiation dose to the patient [3–6]. The dose reference values published by the European Commission, based on studies from 36 European countries, were established using data from standard (average weight) patients with a body weight of 70 ± 15 kg [7]. Therefore, there is still a gap regarding dose reference values for overweight and obese patients in general radiography. Diagnostic reference levels for the most common radiological procedures for average-sized patients have been established in Slovenia, so challenges remain for overweight and obese patients.

The aim of this study was to determine the impact of body mass index (BMI) on dose area product (DAP) and effective dose (ED) for selected imaging procedures in general radiography. The objectives of our study were to determine typical DAP values for overweight and obese patients in the diagnostic department where the study was performed and suggest adjustments to radiological procedures for these patients.

2. Materials and methods

A cross-sectional study was performed, which included data from 597 patients who underwent 1014 examinations performed on Siemens Axiom Aristos FX Plus and Siemens Axiom Aristos VX x-ray units (table 1). The patients were classified into three different groups according to their BMI: Normal weight—Group 1 (18.5–24.99), Overweight—Group 2 (25.0–29.99), and Obese—Group 3 (>30). Prior to the study, approval was obtained from the National Medical Ethics Committee. Each patient was informed about participation in the study and informed consent was obtained from each patient before imaging was performed.

Although both radiographic devices are subject to a systematic quality control program by a medical physicist, additional quality control was performed before the study. The tests performed were related to the tube voltage accuracy and reproducibility, the half-value layer, current–time product linearity, the tube output, total filtration and the DAP meter accuracy. Differences between the displayed and the measured DAP values were less than 10%, so no calibration coefficients for DAP values were used. All results of the above tests were in agreement with the standards [8].

A Siemens Axiom Aristos VX device was used for posteroanterior (PA) and lateral projection in chest imaging. Meanwhile, the Siemens Axiom Aristos FX Plus device was used for imaging the lumbar spine in anteroposterior (AP) and lateral projection, the pelvis in AP projection, the knee in AP and lateral projection, and the shoulder in AP projection. All the imaging projections mentioned are the most frequently performed examinations in the diagnostic department where the study was conducted. The exact number of examinations performed for each imaging protocol and the technical specifications can be found in table 2. Imaging was performed according to the same clinical protocol used daily by radiographers in the radiology department where the study was performed. Considering that image quality is an important factor, all radiographs in our study were of acceptable diagnostic quality as confirmed by the reporting radiologist. The authors of this study did not interfere with or influence the performance of the imaging procedures; they simply collected the data.

For each examination, the size of the image field (primary beam), the distance between the source and the image receiver, and the values of DAP were collated. Patient height and weight were measured, from which the BMI was calculated (table 2).

The Monte Carlo simulation program PCXMC 2.0 (STUK, Radiation and Nuclear Safety Authority of Finland) was used to calculate the ED. During the simulation, the maximum energy of the photons was fixed, and the number of photon particles tracked was one million to reduce the calculation error [9]. Calculations were performed separately for each patient according to exposure parameters, body weight and height, primary field size, position of the central ray and DAP.

Statistical analysis was performed using IBM SPSS statistics 26.0 software (IBM Corporation, USA). The Shapiro–Wilk test was used to determine the normal distribution of the sample. If the data were normally distributed, one-way analysis ANOVA was performed with LSD post-hoc analysis. If the data were not normally distributed, the Kruskal–Wallis test with pairwise comparison and Bonferroni correction analysis was performed to assess differences between BMI groups. In addition, the correlations between BMI and DAP and BMI and ED were determined using the Spearman correlation coefficient, because all the data studied were not normally distributed. Correlation coefficient results of 0.00–0.19 are very weak, 0.20–0.39 are weak, 0.40–0.59 are moderate, 0.60–0.79 are strong and 0.80–1.00 are very strong. Typical DAP values for overweight and obese patients, established for selected imaging protocols, were determined using median values. A significance of $p < 0.05$ was used for all tests.

3. Results

In this study, a total of 1014 examinations (597 patients) were analysed. The normal BMI group consisted of 155 patients, 242 patients were classified into the overweight BMI group, and 200 fell into the obese BMI group. The mean, median and range of values of DAP and ED for the selected imaging protocols are shown in tables 3 and 4, respectively.

Mean DAP values when comparing overweight patients with normal-weight patients showed increased values of 28.9% for PA chest imaging, 58.9% for lateral chest imaging, 62.2% for AP lumbar spine imaging, 59.5% for lateral lumbar spine imaging, and 62.2% for pelvic imaging. When comparing DAP values in

Table 1. Technical specifications of the units used in the study.

X-ray unit	Siemens Axiom Aristos VX	Siemens Axiom Aristos FX plus
Focal spot nominal value (mm)	0.6 and 1.0	0.6 and 1.0
Total filtration (mm)	>2.5 mm Al	>2.5 mm Al
Anti-scatter grid	$r = 15$; 80 cm^{-1}	$r = 15$; 80 cm^{-1}
Detector technology	DR (caesium iodide—CsI)	DR (caesium iodide—CsI)
SID (cm)	180	150

Table 2. Distribution of patients based on BMI and technical parameters in reviewed radiographical procedures.

Imaging protocol	BMI classification	N	Average BMI value (kg m^{-2})	Tube voltage range (kV)	AEC	Average tube load (mAs)	Average imaging field size—at detector plane (cm^2)
PA chest imaging	Normal weight	45	22.2	150	Yes (both lateral chambers)	0.87	1495.4
	Overweight	53	27.5	150		1.18	1576.1
	Obese	61	35.6	150		1.29	1682.4
LAT chest imaging	Normal weight	45	22.2	150	Yes (central chamber)	1.59	1319.6
	Overweight	53	27.5	150		2.67	1425.7
	Obese	61	35.6	150		3.55	1610.5
AP lumbar spine imaging	Normal weight	44	22.8	79–81	Yes (central chamber)	19.91	910.8
	Overweight	69	27.4	79–85		30.55	945.5
	Obese	45	33.3	79–96		55.72	955.9
LAT lumbar spine imaging	Normal weight	44	22.8	90–96	Yes (central chambers)	29.58	830.2
	Overweight	69	27.4	90–100		43.93	902.5
	Obese	45	33.3	90–102		55.28	903.2
AP pelvic imaging	Normal weight	20	22.9	81–83	Yes (central chambers)	26.12	1519.6
	Overweight	43	27.0	81–87.5		40.37	1585.1
	Obese	37	33.8	81–96		80.51	1639.8
AP knee imaging	Normal weight	22	23.2	63	No (manual exposure)	3.83	435.5
	Overweight	42	27.6	63		3.83	435.5
	Obese	36	33.4	63		3.83	439.9
LAT knee imaging	Normal weight	22	23.2	64.5	No (manual exposure)	4.20	440.0
	Overweight	42	27.6	64.5		4.20	443.5
	Obese	36	33.4	64.5		4.20	445.0
AP shoulder imaging	Normal weight	24	22.6	66	No (manual exposure)	7.34	292.0
	Overweight	35	27.6	66		7.34	308.9
	Obese	21	34.5	66		7.34	320.7

obese patients compared to normal-weight patients, the increase in DAP values was 95.2% for PA chest imaging, 215.3% for lateral chest imaging, 227.2% for AP lumbar spine imaging, 117.3% for lateral lumbar spine imaging, and 275.4% for pelvic imaging. There was little or no difference in DAP values for knee imaging in both projections or for shoulder imaging in the AP projection.

Statistically significant differences in DAP values were observed among all three groups studied in the case of chest imaging in the PA and lateral projections and for lumbar imaging in the AP and lateral projections ($p < 0.001$). In the case of pelvic imaging, a statistically significant difference was found between all three groups in the AP projection ($p < 0.001$). Post-hoc analysis showed a statistically significant difference when comparing the group of normal-weight patients with the group of overweight patients ($p = 0.004$), normal-weight patients compared to obese patients and overweight patients compared to obese patients had the same value ($p < 0.001$). In the case of knee imaging, the test showed no statistically significant differences in either the AP or lateral projections ($p = 0.656$; $p = 0.178$). Similar results were found for AP shoulder imaging ($p = 0.502$).

The mean ED for overweight patients increased by 11.0% for the PA chest imaging, 39.4% for lateral chest imaging, 37.4% for AP lumbar spine imaging, 27.5% for lateral lumbar spine imaging and 56.0% for pelvic imaging compared to normal-weight patients.

Table 3. Mean, median and range of DAP values for reviewed procedures.

BMI groups	Mean (μ Gym^2)	Standard deviation (μ Gym^2)	Median (μ Gym^2)	Minimum (μ Gym^2)	Maximum (μ Gym^2)
Chest imaging—PA projection					
Normal weight	2.73	0.45	2.70	2.00	3.80
Overweight	3.52	0.75	3.40	2.50	6.50
Obese	5.33	1.62	4.80	3.20	10.20
Chest imaging—lateral projection					
Normal weight	5.28	1.75	4.90	2.60	10.70
Overweight	8.39	3.39	7.20	3.80	17.50
Obese	16.65	8.12	14.40	5.90	44.79
Lumbar spine imaging—AP projection					
Normal weight	37.03	18.11	31.60	14.90	89.20
Overweight	60.08	27.73	55.40	29.60	189.30
Obese	121.18	81.53	95.90	39.10	496.80
Lumbar spine imaging—lateral projection					
Normal weight	45.55	19.63	44.30	15.90	123.50
Overweight	72.66	27.74	69.60	32.70	162.80
Obese	98.98	32.44	88.30	52.20	176.00
Pelvic imaging					
Normal weight	55.72	20.20	54.80	28.90	104.40
Overweight	90.39	26.17	87.60	25.09	179.50
Obese	209.18	113.98	172.50	83.20	727.10
Knee imaging—AP projection					
Normal weight	4.30	0.64	4.30	3.00	6.60
Overweight	4.21	0.42	4.25	3.20	5.00
Obese	4.31	0.43	4.30	3.60	5.10
Knee imaging—lateral projection					
Normal weight	2.26	0.49	2.20	1.80	4.40
Overweight	2.23	0.18	2.20	1.90	2.80
Obese	2.27	0.25	2.20	1.80	3.10
Shoulder imaging					
Normal weight	5.50	1.15	5.20	3.30	8.20
Overweight	5.40	1.12	5.20	3.30	7.50
Obese	5.75	1.01	5.80	4.00	7.90

When comparing ED values in obese patients versus normal-weight patients, the increase in DAP values was 32.3% for PA chest imaging, 123.4% for lateral chest imaging, 129.0% for AP lumbar spine imaging, 34.8% for lateral lumbar spine imaging and 241.9% for pelvic imaging. As with the DAP values, there were no significant differences in the case of ED of knee imaging in both projections or for shoulder imaging in the AP projection.

Statistical analysis revealed significant differences in the ED in the case of chest imaging in the PA projection ($p < 0.001$). Post-hoc analysis revealed statistically significant differences between all three pairs (normal weight vs. overweight; normal weight vs. obese, overweight vs. obese) ($p = 0.003$; $p < 0.001$; $p < 0.001$). With chest imaging in the lateral projection, statistically significant differences were found in all three weight pairs ($p < 0.001$). Similar results were found when observing lumbar spine imaging in the AP projection. The statistical test showed statistically significant differences ($p < 0.001$) and the post-hoc analysis showed differences between all three pairs ($p = 0.003$; $p < 0.001$; $p < 0.001$). Lateral projection showed statistically significant differences in the cases of normal weightvs. overweight and normal weight vs. obese patients ($p = 0.002$; $p < 0.001$). Pelvic imaging again showed statistically significant differences between all three pairs ($p < 0.001$; $p = 0.007$; $p < 0.001$).

To evaluate the effect of BMI on the DAP and the ED values, a Spearman's correlation coefficient was obtained. The results are presented in table 5.

In order to encourage further optimisation at the department, typical radiation quantity values were introduced and are listed in table 6.

Table 4. Mean, median and range of ED values for reviewed procedures.

BMI groups	Mean (μ Sv)	Standard deviation (μ Sv)	Median (μ Sv)	Minimum (μ Sv)	Maximum (μ Sv)
Chest imaging—PA projection					
Normal weight	8.94	1.05	8.72	6.94	11.74
Overweight	9.92	1.44	9.65	7.25	15.31
Obese	11.83	2.44	11.47	7.98	17.98
Chest imaging—lateral projection					
Normal weight	13.70	3.73	12.99	8.27	28.80
Overweight	19.10	6.97	16.92	11.23	40.85
Obese	30.61	11.66	28.22	13.87	65.30
Lumbar spine imaging—AP projection					
Normal weight	126.78	50.03	117.52	65.05	275.13
Overweight	174.14	72.15	153.53	85.47	550.59
Obese	290.28	151.68	256.67	102.45	862.09
Lumbar spine imaging—lateral projection					
Normal weight	75.57	27.88	73.19	32.25	163.06
Overweight	96.32	31.5	87.96	52.08	179.91
Obese	101.86	24.78	99.73	54.85	159.06
Pelvic imaging					
Normal weight	100.17	34.35	101.39	29.89	172.77
Overweight	156.22	40.84	154.36	35.30	257.58
Obese	342.48	161.75	307.65	147.06	1079.50
Knee imaging—AP projection					
Normal weight	0.15	0.02	0.16	0.12	0.21
Overweight	0.15	0.02	0.14	0.10	0.18
Obese	0.14	0.02	0.14	0.11	0.17
Knee imaging—lateral projection					
Normal weight	0.12	0.01	0.11	0.10	0.16
Overweight	0.11	0.01	0.11	0.09	0.13
Obese	0.10	0.01	0.10	0.08	0.12
Shoulder imaging					
Normal weight	1.25	1.11	0.94	0.52	2.69
Overweight	0.92	0.62	0.77	0.33	2.52
Obese	0.80	0.28	0.75	0.47	1.78

Table 5. Correlation coefficients between BMI and DAP value, and BMI and ED value.

	Correlation between BMI and DAP			Correlation between BMI and ED		
Imaging protocol	Correlation coefficient	p-value	Result	Correlation coefficient	p-value	Result
PA chest imaging	0.836	<0.001	Very strong positive correlation	0.615	<0.001	Strong positive correlation
LAT chest imaging	0.830	<0.001	Very strong positive correlation	0.744	<0.001	Strong positive correlation
AP lumbar spine imaging	0.762	<0.001	Strong positive correlation	0.691	<0.001	Strong positive correlation
LAT lumbar spine imaging	0.656	<0.001	Strong positive correlation	0.320	<0.001	Weak positive correlation
AP pelvic imaging	0.899	<0.001	Very strong positive correlation	0.888	<0.001	Very strong positive correlation
AP knee imaging	0.114	0.259	Very weak positive correlation	−0.331	0.001	Weak negative correlation
LAT knee imaging	0.203	0.042	Weak positive correlation	−0.453	<0.001	Moderate negative correlation
AP shoulder imaging	0.087	0.444	Moderate positive correlation	−0.335	0.002	Weak negative correlation

Table 6. Typical DAP and ED values for three different types of body constitution.

	Normal weight		Overweight		Obese	
	DAP (μ Gym^2)	ED (μ Sv)	DAP (μ Gym^2)	ED (μ Sv)	DAP (μ Gym^2)	ED (μ Sv)
Chest imaging—PA projection	2.7	8.7	3.4	9.7	4.8	11.5
Chest imaging—lateral projection	4.9	13.0	7.2	16.9	14.4	28.2
Lumbar spine imaging—AP projection	31.6	117.5	55.4	153.5	95.9	256.7
Lumbar spine imaging—lateral projection	44.3	73.2	69.6	88.0	88.3	99.7
Pelvic imaging	54.8	101.4	87.6	154.4	172.5	307.7
Knee imaging—AP projection	4.3	0.2	4.3	0.1	4.3	0.1
Knee imaging—lateral projection	2.2	0.1	2.2	0.1	2.2	0.1
Shoulder imaging	5.2	0.9	5.2	0.8	5.8	0.5

4. Discussion

In this study, we aimed to evaluate the effects of BMI on the DAP and ED values in selected imaging protocols in general radiography.

The average increase in DAP values in overweight patients compared with normal-weight patients for PA chest imaging, lateral chest imaging, AP lumbar spine imaging, lateral lumbar spine imaging and pelvic imaging was 28.9%, 58.9%, 62.2%, 59.5% and 62.2%, respectively. The DAP values in obese patients compared with normal-weight patients resulted in dose increases of 95.2%, 215.3%, 227.2%, 117.3% and 275.4%, respectively. DAP values for imaging of the knee and AP imaging of the shoulder showed no statistical differences. This was due to the use of manual exposure parameters in the mentioned imaging protocols. In the study by Tung *et al* [5], the increase when comparing the DAP value between normal-weight and overweight patients was 57.1%, 71.0%, 123.1%, 87.5% and 72.8% for PA chest imaging, chest imaging in lateral projection, AP imaging of the lumbar spine, imaging of the lateral lumbar spine and imaging of the pelvis, respectively. The increase in DAP values when comparing the average DAP values between normal and obese patients was 157%, 196.8%, 391.0%, 273.3% and 194.2% for the same order of the above imaging protocols.

The differences in the increase in DAP values are due to the different choice of exposure parameters. The lower dose increase is probably due to the higher tube voltage used in our study, a different distribution of adipose tissue, and exact patient positioning compared to the study by Metaxas *et al* [3].

Pascoal *et al* [10] reported that the overall effect of tube voltage on image quality and ED for chest radiography depends on patient size, and that a single value for tube voltage cannot be considered optimal for imaging all patients. The results of our study in the case of ED are in agreement with the above-mentioned study, but we must point out that in our study the image quality was not evaluated from a methodological point of view.

A very strong positive correlation was found between the BMI and DAP values in the case of chest imaging in both projections ($r = 0.836$ and $r = 0.830$) and pelvic imaging ($r = 0.899$); a strong positive correlation was found for lumbar spine AP projection ($r = 0.762$) and lateral projection ($r = 0.656$). In the study by Metaxas *et al* [3], a strong correlation was found in the cases of PA chest imaging ($r = 0.772$), lateral chest imaging ($r = 0.668$) and pelvic imaging ($r = 0.716$), and a very strong correlation in the case of AP lumbar spine imaging ($r = 0.856$) and lateral lumbar spine imaging ($r = 0.900$). Their results regarding the influence of BMI on DAP values are similar to those in our study.

The correlation between BMI and ED showed a weak positive correlation for lateral lumbar spine projection ($r = 0.320$), a positive strong correlation for chest imaging PA ($r = 0.615$), lateral chest imaging ($r = 0.744$) and lumbar spine imaging AP ($r = 0.691$), and a very strong positive correlation for pelvic imaging ($r = 0.888$). The correlation results between BMI and ED in pelvic imaging were similar to the results of Zalokar *et al* [11].

For optimisation of radiological procedures, it is essential to also estimate the ED during such examinations since this quantity is more meaningful than the DAP values regarding the biological effects of radiation. We would like to draw attention to the limitation of ED estimation in our study. Namely, we did not evaluate the amount and distribution of adipose tissue in overweight and obese patients. For better evaluation of ED, the diameter and/or circumference of the patient habitus along the central axis of the x-ray beam should also be collected in order to adjust the ED calculation.

Another limitation of this study is that we did not use any objective measures like signal-to-noise ratio or contrast-to-noise ratio to assess the quality of the radiographs; however, being aware of the importance of image quality, we only used radiographs that were deemed diagnostically acceptable by the reporting radiologist. A further limitationis that the results describe data only from one of the Slovenian hospitals. The limitations of the PCXMC 2.0 software must also be mentioned; the software does not provide the ability to distribute the adipose tissue and change the patient position (upright or supine) and its influence on the adipose tissue.

To allow comparison of clinical practice between different radiology departments, a set of typical DAP and ED values for different body types was also determined using the median values of the DAP and ED, respectively. The established typical values for overweight and obese patients are even lower than the diagnostic reference level values established by the European Commission [12], which were established for standard-size patients. This is due to fact that the radiology department where the study was conducted has one of the lowest dose levels for general x-ray procedures in the country due to the higher tube voltage techniques used.

5. Conclusions

We can conclude that BMI and body type (overweight and obese) have a strong influence on the radiation dose received by patients (DAP and ED). In our study, the average increase in DAP value in overweight patients ranged from 28.9% to 62.2%, whereas the increase in DAP in obese patients ranged from 95.2% to 275.4%. In the case of ED, the relative increase was smaller compared with DAP. The increase of ED in overweight patients ranged from 11.0% to 56.0% and the increase in obese patients ranged from 32.3% to 241.9%. This influence was confirmed by Spearman's correlation coefficient, which showed a strong to very strong correlation between BMI and DAP for examinations in the torso region of the body. Between BMI and ED, the correlation was moderate to very strong.

Since the dose received by the patient is highly dependent on BMI or, in other words, body type, it is critical to establish separate dose reference values for overweight and obese patients. This will then also highlight the potential opportunities to optimise exposure parameters for overweight and obese patients to reduce the radiation dose received. Higher tube voltage techniques are one of the possible clinical practice adaptations that can be used in overweight and obese patients, taking care not to compromise the acceptable level of image quality.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Conflict of interest

The authors declare no conflict of interest.

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References

[1] WHO *World Health Organization Obesity and overweight* (available at: www.who.int/news-room/fact-sheets/detail/obesity-and-overweight) (Accessed 19 September 2019)

[2] Nacionalni inštitut za javno zdravje 2018 *Determinante zdravja—dejavniki tveganja* (available at: www.nijz.si/sites/www.nijz.si/files/uploaded/publikacije/letopisi/2018/3.2_cezmerna_hranjenost_in_debelost_2018.pdf) (Accessed 17 January 2022)

[3] Metaxas V I, Messaris G A, Lekatou A N, Petsas T G and Panayiotakis G S 2019 Patient dose in digital radiography utilising BMI classification *Radiat. Prot. Dosim.* **184** 155–67

[4] Uppot R N 2007 Impact of obesity on radiology *Radiol. Clin. North Am.* **45** 231–46

[5] Tung C J, Lee C J, Tsai H Y, Tsai S F and Chen I J 2008 Body size-dependent patient effective dose for diagnostic radiography *Radiat. Meas.* **43** 1008–11

[6] Le N T T, Robinson J and Lewis S J 2015 Obese patients and radiography literature: what do we know about a big issue? *J. Med. Radiat. Sci.* **62** 132–41
[7] European Union 2015 *Diagnostic Reference Levels in Thirty-Six European Countries. Part 1/2*
[8] Hiles P A, Mackenzie A, Scally A and Wall B 2005 *Recommended Standards for the Routine Performance Testing of Diagnostic X-ray Imaging Systems; Repot 91* (York: Institute of Physics and Engineering in Medicine)
[9] Chaparian A, Kanani A and Baghbanian M 2014 Reduction of radiation risks in patients undergoing some x-ray examinations by using optimal projections: a Monte Carlo program-based mathematical calculation *J. Med. Phys.* **39** 32–9
[10] Pascoal A, Patel R, Lawinski C and Tabakov S 2005 Optimization of tube voltage and dose for digital chest radiography—a study addressing patient size *Proc. UK Radiological Congress* (*Birmingham*, *6–8 June 2005*) p 2
[11] Zalokar N, Resnik A and Mekiš N 2020 Radiation dose during pelvic radiography in relation to body mass index *Radiat. Prot. Dosim.* **189** 294–303
[12] European Union 2015 *Diagnostic Reference Levels in Thirty-six European Countries. Part 2/2*