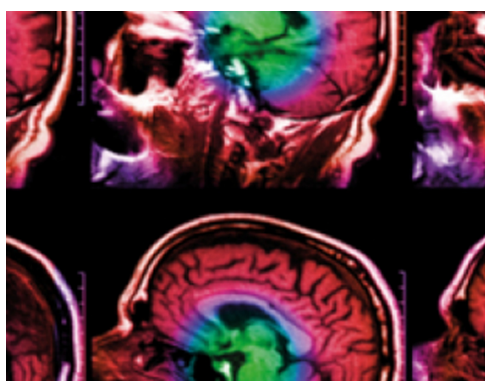


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Increased radiation dose and projected radiation-related lifetime cancer risk in patients with obesity due to projection radiography

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Abstract

Purpose. Primarily to evaluate the radiation dose delivered to patients with obesity in projection radiography and its relationship to the patient's size. A secondary purpose is to estimate the subsequent projected radiation-related lifetime cancer risk to patients with obesity compared to normal-weight patients. *Method and material.* Data from 1964 patients from a bariatric clinic in the UK were reviewed with the relevant permission. 630 patients were identified to have a projection radiography history and were included in the study. Patients' dose area product (DAP) data were collected for all projection radiography. Multiple exams in one day including a single DAP reading and



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exams with no records of DAP and exposure factors were excluded. Correlations were calculated and data analysed to yield the third quartile for each examination using STATA 14. Absorbed doses were generated from PCXMC simulation, utilising DAP data from this study and the UK national diagnostic reference level (NDRL), to calculate the effective risk for patients with obesity compared to patients with normal-weight. *Results.* Patients with obesity received higher DAPs for all examinations included in this study compared to NDRL. Abdominal and lumbar spine radiographs DAPs were the highest (17.6 and 30.31 Gy cm²) compared to the NDRL (2.5 and 4 Gy cm²). Only moderate to low correlations were found between patient's size and DAPs in the abdomen and chest radiographs. The projected radiation-related lifetime cancer risk for patients with obesity is up to 153% higher than for adult patients with normal weight. *Conclusion.* Patients with obesity receive higher DAPs than normal-weight adults which may be in excess of that expected due to their size. Therefore, radiation-related lifetime cancer risk is increased in patients with obesity as a result of medical radiation exposures. This indicates more dose optimisation research is needed in this group of patients to reduce dose rate and variation.

Keywords: radiation dose, obesity, effective risk, radiography

Introduction

Medical imaging is by far the largest man-made source of ionising radiation delivered to the general population [1]. It accounts for 15% of the radiation dose from both natural and artificial sources and 90% of the artificial source alone [2]. In England, approximately 40.7 million radiographic procedures were carried out in the year between March 2015 and March 2016, of a projected population of 54.4 million [3, 4]. More than half (22.6 million) of these were projection radiography examinations. The x-rays used in medical imaging are a form of ionising radiation, that have sufficient energy when interacting with human tissues to result in ionisation and or excitation [5, 6]. This has the potential to cause damage to the exposed tissue and result in cell mutation or apoptosis. The higher the radiation dose, the more likely that tissue damage will occur. This is known as a stochastic effect which occurs in low dose procedures, such as projection radiography where there is no safe limit of radiation dose based on the 'linear no-threshold' model. This model is considered by many regulatory and advisory groups as a scientifically valid approach [7, 8], hence it underpins radiation protection in medical imaging where the dose should be kept as low as reasonably practicable (ALARP) [9]. In order to comply with this principle, the International Commission of Radiological Protection (ICRP) introduced the term 'diagnostic reference level' (DRL) in 1996, which is a quality assurance (QA) tool to investigate the radiation dose delivered to different patients for the same procedure [10]. This was adapted by the ICRP after the concept 'reference dose' for common projection radiographic procedures was introduced in the UK in 1990 [11]. In the UK, under the Ionising Radiation(Medical Exposure)Regulation 2000 (IRMER, 2000), the hospital employer is required by law to set a DRL and ensure it is followed and adhered to [9]. The most recent review of the national DRL in the UK was conducted in 2010 to maintain and monitor radiation doses to the UK population, and it was based on mean patient's weight per x-ray room, which ranges between 65 and 75 kg [2]. This weight range represents the standard size-patient, but not patients with obesity [2].

However, in the last few decades, the prevalence of obesity has risen with the developed countries leading and developing countries following [12]. Internationally, 1.46 billion adults are overweight, of them 502 million are obese [13]. In the UK, around a quarter of the adult population are obese, with the prevalence in females higher than in males except in Northern Ireland where males tend to be heavier [14]. Due to the limitations incurred by physical size and body composition variation compared to adult patients with normal weight, obesity poses a challenge in patient's assessment and management in hospital [15]. The ability to achieve an adequate clinical examination is compromised in this population [16]. Likewise, it becomes difficult to listen to heart sounds, lung respiration and bowel sounds [16]. Additionally, the capability to palpate the abdomen, perform a clinical pelvic examination and evaluate for masses is compromised in clinical practice [16]. These in turn have increased reliance on other health care assessments, including medical imaging, for this substantial group of people [16]. Due to the recognised obesity comorbidities [17–20], patients with obesity are more likely to present for health assessment than their normal-weight peers.

As a result, literature has emerged recently reporting the challenges facing radiology departments managing patients with obesity. In the context of radiation protection, patients with obesity are receiving higher doses as a result of computed tomography (CT) and interventional procedures [21–24]. However, in projection radiography, the dose to patients with obesity in clinical practice has yet to be reported. With the high prevalence of obesity and the amount of radiographic exposures conducted annually as discussed earlier, it is of high importance to explore the actual radiation dose delivered to obese patient during projection radiography. Likewise, the literature is lacking radiation dose data for the other group of patients, who are excessively underweight and could be at a higher risk; however, this study focused on patients with obesity where the literature has already reported high doses delivered in other modalities [21–24].

This study aimed to explore the ionising radiation dose area product (DAP) received by patients with obesity during projection radiography; to identify any link between the DAP received and patient's anthropometrics and to estimate the subsequent projected radiation-related lifetime cancer risk based on the reported DAPs for patients with obesity compared to national dose data for patients with normal weight. Due to the nature of the study, retrospective, image quality was not investigated. However, a previous study [25] has reported an increase in the number of habitus-limited radiology reports between 1989 and 2003 in the USA.

Materials and methods

Ethical approval

Ethical approval was not required according to the research and development department in the hospital. Permission was granted to conduct the study as a service evaluation.

Patients

A list of 1964 patients with obesity, based on the World Health Organisation [26] criteria, of a body mass index (BMI) equal to, or over, 30 kg m^{-2} , was provided from a bariatric surgeon in the hospital, which is considered as the largest bariatric centre in the region. All patients had visited the bariatric surgery clinic and undergone a bariatric surgery procedure. The list contained the patients' hospital number, height (m), weight (kg) and BMI (kg m^{-2}). All anthropometric measures were completed prior to the patient undergoing bariatric surgery.

The age of the patients at the time of their radiography examination was determined from their date of birth subtracted from the date of the radiography exam.

Inclusion and exclusion criteria

All data provided by the bariatric surgeon were for patients with obesity, and hence, they were eligible for the study. Files were screened and any projection radiography procedure was included unless: the DAP or its unit was missing; the procedure did not match the NDRL criteria in terms of the number and types of projections; if the DAP reading was recorded once for multiple radiographic exams and if the exposure factors were not recorded.

As the study aimed to compare the DAP to the NDRL, only the radiographic examinations for which the NDRL had been calculated were considered. In the abdomen, only patients with an anteroposterior (AP) were included. As noted in the picture archiving and communication system (PACS), radiographers usually perform abdominal radiographs using two images, and occasionally three images, but enter one DAP reading in the radiology information system (RIS). This is justifiable by the fact that the largest image receptor, which is 35 cm × 43 cm, cannot accommodate the whole abdomen. For this reason, whether the patient had two or three images to cover the abdominal area, it was considered as an AP projection, and hence analysed and compared to the NDRL. In the chest, the analysis was restricted to the posteroanterior (PA) projection. In the pelvis, patients with AP projection only were included. In the lumbar and cervical spine, if the patients had AP and lateral (LAT) projections only, then they were eligible for the study. This is attributed to the availability of DAP for AP and lateral in the NDRL, which was combined for each procedure and then compared to the DAP result from this data. Other procedures were considered but not included in the study as they had no DAP comparator in the NDRL, For example; knee, shoulder, foot and all other extremity procedures. Thoracic spine was also excluded since the collected data were fewer than 10 patients and most of them had one DAP for multiple projections. As the study was conducted retrospectively in a clinical environment, the DAP dosimeters were assumed to be maintained and had a QA regime following current legislation and hospital standard operating procedures.

Obtaining the data

Patients' hospital numbers were entered into the RIS (Carestream Vue RIS, Version 11.0.12.51) to open the radiology file and the DAP reading was accessible through exam details. The unit of the DAP reading, for each exam and patient, was recorded along with the DAP value.

In order to reduce the human errors during the data recording, several rules were followed during the data transition. To confirm the file belonged to the right patient, two checks were used: the hospital number and the patient age. The DAP unit for each entry was recorded as it appears in the RIS, and then converted to Gray cm² prior to the analysis. To check the procedure matches the DRL criteria in terms of number and type of projections, PACS (VUE PACS version 12.0.0.8902) was used to access the images and confirm the eligibility of each procedure. The data were recorded separately in excel sheets for each examination.

Data analysis

The mean, median, standard deviation, minimum and maximum were calculated for age, height, weight, BMI and DAP. Any outlying values were investigated and errors were corrected after re-checking patient details again before the final analysis. The statistical analysis

was performed using STATA 14. Histograms of the anthropometric measures demonstrated the data were not normally distributed. For this reason, Spearman's correlation was conducted to investigate the relation between the DAP in each procedure and the participants' age, height, weight and BMI.

Dose modelling

A PC programme for x-ray Monte Carlo (PCXMC 2.0—STUK-Radiation and Nuclear Safety Authority, Helsinki, Finland) was used to model the mean organ absorbed doses. PCXMC is a computer programme for calculating patients' organ absorbed doses and effective dose from radiology examinations. It has a flexible stylized phantom to freely adjust for the x-ray projection and other examination conditions of projection radiography and fluoroscopy. The anatomical data of the phantom are based on the mathematical hermaphrodite phantom models of Cristy and Eckerman, with some modifications and user-adjustable phantom sizes [27, 28]. The PCXMC is widely used in the literature for absorbed dose estimation in normal-weight adult and paediatric [29, 30]. In high BMI groups of patients, PCXMC has already been validated against voxel phantom [31], which showed a similar trend to hybrid phantom in absorbed dose inverse relationship with BMI.

The organ absorbed doses were estimated for the five radiography procedures reported in this study compared with the 2010 NDRL review [2]. The phantom size and exposure parameters for both groups were adjusted based on the reported value of each parameter. For the normal-weight group, the size was adjusted in terms of weight (kg) according to the mean weight in 2010 NDRL review. The height was set to the standard height in the PCXMC, 178.6 (cm) for the same group. With regards to patient with obesity, the height (cm) and weight (kg) were set to the median value in each radiograph as they were not normally distributed. The x-ray beam projection, size and collimation were adjusted as appropriate for the examination. Likewise, the x-ray spectrum was adjusted through appropriate selection of the x-ray tube voltage, as reported for the two groups, filtration and anode angle (table 1).

Focal to image distance (FID) was set to the standard figure for each procedure as described by Bontrager and Lampignano [32], but this may not reflect what was used clinically in the hospital as such measurement is not recordable in either RIS or PACS. The FSD is then calculated by subtracting the phantom thickness from the FID.

The median DAP (mGy cm^2) reported in the NDRL 2010 review and in this study was used in the calculation by PCXMC [2]. However, the standard practice at the sites involved in this study was to input a single DAP reading for the imaging series. The DAP for lumbar spine was extracted from the RIS as one number for both views, AP and LAT, and similarly for cervical spine. For this reason, the combined DAP of lumbar spine AP and LAT, from the 2010 review, was used as a benchmark to determine the percentage of DAP for each view separately [2]. As a result, the AP represents 37.5% of the combined median DAP for AP and LAT while the LAT view represents 62.5%. Likewise for cervical spine examinations, the AP view represents 50% and the LAT view represents 50% of combined median DAP value. While this provides some limitations to this study, it does still provide an indication of the risk an obese patient is subjected to and is comparable with the NDRLs. The use of DAPs reported in the NDRL rather than the local DRL is due to the fact that NDRL values are derived from large data across the country which reflects common practice. Additionally, the combined average local DRL for the five reported procedures is 32% below the combined NDRL for the same procedures. In order to reduce the errors in organ absorbed dose estimation, the number of photons was set to one million.

Table 1. PCXMC exposure details for NDRL and obese patients groups.

		Weight (kg)	Height (cm)	FSD (cm)	Tube voltage (kVp)	Filtration (Al mm)	X-ray beam width (cm)	X-ray beam height (cm)	Arms in phantom	Dose value (DAP) (Gy cm ²)	
Abdomen (AP)	NDRL	71	178.6	82	77	3.1	34	43	no	1.8	
	Obese	Upper abdomen	141.55	166	75	80	3.1	46	30	no	4.445
		Lower abdomen	141.55	166	75	80	3.1	45	28	no	4.445
Chest (PA)	NDRL	70	178.6	160	90	3.1	34	28	no	0.08	
	Obese	125	165	153	120	3.1	48	30	no	0.156	
Pelvis (AP)	NDRL	71	178.6	80	75	3.1	34	32	no	1.7	
	Obese	125	168	76	75	3.1	44	33	no	3.46	
Lumbar spine (AP)	NDRL	71	178.6	80	79	3.1	16	35	no	1.2	
	Obese	126.25	168	75	80	3.1	18	35	no	3.9	
Lumbar spine (LAT)	NDRL	71	178.6	70	88	3.1	15	25	no	1.9	
	Obese	126.25	168	54	94	3.1	18	25	no	6.5	
Cervical spine (AP)	NDRL	71	178.6	90	68	3	14	20	yes	0.1	
	Obese	119	165	87	65	3	15	20	yes	0.145	
Cervical spine (LAT)	NDRL	71	178.6	177	72	3	13	24	yes	0.1	
	Obese	119	165	172	72	3	15	26	yes	0.145	

PCXMC: A PC programme for x-ray Monte Carlo simulation software.

FSD: Focus to skin distance.

NDRL: National diagnostic reference level.

kVp: Peak kilovoltage.

AP: Anteroposterior.

PA: Posteroanterior.

LAT: Lateral.

Radiation-related lifetime cancer risk estimation

The radiation-related lifetime cancer risk was calculated as described by Brenner [33], where he proposed the use of effective risk instead of effective dose to calculate the risk of cancer as a result of ionising radiation exposure. The equation of effective risk calculation is similar to that of effective dose. The difference is that the tissue weighting factor in the effective dose equation was replaced with organ-specific radiation-induced cancer risk, such as those published by The Nuclear and Radiation studies board (BEIR VII) and the report by the Health Protection Agency [34, 35]. However, the argument about effective risk and effective dose utilisation in cancer risk estimation is beyond the scope of this paper and already reported in the literature [33, 34, 36].

In this study, the age and sex specific radiation-related lifetime cancer risk figures reported by Wall *et al* [34], was used in effective risk calculation. The sum of the product of the estimated organ dose (mGy) and the radiation-related lifetime cancer risk incidence for that organ (percentage per mGy) gave the effective risk. The effective risk for each examination was calculated as described in Wall *et al* [34, 35]. The age was set from 20 years and above, as our data shows very few patients under 20.

Results

Of 1964 patients with obesity, 1225 files were excluded for technical issues such as; repeated file number, no radiology file existed, different file ID format and files with multiple patients' names. The remaining 739 files were screened and 630 of them showed history of projection radiography while 109 showed no history. Table 2 summarises the characteristics of patients' anthropometry for each procedure.

This includes patients who met the criteria of the NDRL for each procedure in terms of types of view. Among the patients with obesity in our sample are young patients, less than 20 years age. Also, radiographers are managing patients with a BMI of 98.2 kg m^{-2} , as this cohort shows.

Table 3 summarises the radiation dose (DAP) received by patients with obesity for each procedure. The 75th percentile DAP for lumbar spine (AP + LAT) and abdomen (AP) are the highest while the chest (PA) is the lowest, as table 3 shows.

For comparison purposes, the 75th percentile of the DAP was reported and compared to the NDRL in table 3. The NDRL was based on a mean patient weight of 65–75 kg. As shown in table 3, patients with obesity were exposed to a significantly higher DAP especially in lumbar, abdomen and pelvis radiograph. The difference percentage between 75th percentile of the DAP for abdomen AP is 604% higher in patients with obesity compared to patients with normal-weight. In lumbar spine, the difference reached up to 657% higher in patients with obesity.

Since the patient's doses are dependent on the patient size [37], the relationship between the DAP and the patients' anthropometrics was tested. As shown in table (4), weak to moderate correlations were found between DAP in chest and abdomen with patient's size.

The DAP was correlated moderately with patients weight in abdomen AP, $r (n = 50) = 0.52$, $p < 0.0001$. However, only a weak correlation was found between abdomen DAP and height $r (n = 50) = 0.38$, $p < 0.01$, and BMI, $r (n = 50) = 0.42$ $p < 0.005$. In Chest PA, the DAP correlated weakly with weight, $r (n = 183) = 0.25$ $p < 0.005$, BMI $r (n = 183) = 0.20$ $p < 0.005$, and height $r (n = 183) = 0.15$ $p < 0.05$. No correlations were found between patient anthropometrics and DAP in the remaining procedures.

Table 2. Patients' characteristics.

	Number		Age (year)	Height (m)	Weight (kg)	BMI (kg m ⁻²)
Abdomen (AP)	50	Mean ± SD	48 ± 12.5	1.66 ± 0.1	142.39 ± 29.19	50.71 ± 8.36
		Median (min–max)	47.57 (19.7–75.2)	1.66 (1.4–1.93)	141 (81.4–222)	50.25 (32.6–69.7)
Chest (PA)	183	Mean ± SD	47.98 ± 10.78	1.67 ± 0.09	140.16 ± 30.57	49.86 ± 8.94
		Median (min–max)	48.46 (18–70.2)	1.65 (1.48–1.96)	136 (81.4–301.6)	48.8 (34.5–98.5)
Pelvis (AP)	27	Mean ± SD	55.22 ± 8.34	1.67 ± 0.08	130.09 ± 25.30	46.02 ± 6.65
		Median (min–max)	55.70 (43.2–83.13)	1.68 (1.52–1.84)	125 (91.6–199)	45.2 (35.8–59.4)
Lumbar spine (AP and LAT)	34	Mean ± SD	47.43 ± 12.58	1.68 ± 0.11	129.33 ± 27	45.57 ± 7.37
		Median (min–max)	46.30 (19.37–83.20)	1.68 (1.48–1.98)	126.2 (78.5–186)	44 (30.7–61)
Cervical spine (AP and LAT)	16	Mean ± SD	53.24 ± 10.88	1.64 ± 0.08	124.95 ± 26.39	45.77 ± 7.68
		Median (min–max)	55.15 (27.27–70.18)	1.65 (1.5–1.83)	118.8 (85.7–177.8)	44.4 (35.8–59.4)

SD: Standard deviation.

AP: Anteroposterior.

PA: Posteroanterior.

LAT: Lateral.

BMI: Body mass index.

Table 3. Dose area product (DAP) for the patients with obesity and the NDRL with percentage increase between the NDRL and 75th percentile DAP values.

	DAP (Gy cm ²)							
	Mean	Min.	Max.	1st quartile	Median	75th percentile	NDRL	Increase %
Abdomen (AP) <i>n</i> = 50	21.09	0.13	431.12	3.59	8.89	17.6	2.5	604%
Chest (PA) <i>n</i> = 183	0.33	0.007	6.81	0.08	0.15	0.32	0.15	133%
Pelvis (AP) <i>n</i> = 27	5.1	0.078	21.48	1.12	3.46	5.69	2.2	158.6%
Lumbar spine (AP and Lt) <i>n</i> = 34	26.57	0.43	181	3.70	10.40	30.31	4	657%
Cervical spine (AP and Lt) <i>n</i> = 16	0.80	0.02	6.73	0.08	0.2	0.9	0.31	200%

NDRL: National diagnostic reference level.

n = number.

AP: Anteroposterior.

PA: Posteroanterior.

LAT: Lateral.

Table 4. Spearman correlation between DAP and patients' anthropometrics.

	Age (year)			Height (m)			Weight (kg)			BMI (kg m ⁻²)		
	<i>n</i>	<i>r</i>	<i>P</i>	<i>n</i>	<i>r</i>	<i>P</i>	<i>n</i>	<i>r</i>	<i>P</i>	<i>n</i>	<i>r</i>	<i>P</i>
Abdomen	50	-0.07	0.61	50	0.38	0.006	50	0.52	0.0001	50	0.42	0.002
Chest	183	-0.05	0.42	183	0.15	0.035	183	0.25	0.0005	183	0.20	0.005
Pelvis	27	-0.17	0.37	27	0.06	0.74	27	0.10	0.60	27	-0.15	0.44
Lumbar spine	34	-0.01	0.93	34	0.22	0.2	34	0.14	0.41	34	-0.02	0.90
Cervical spine	18	-0.05	0.84	18	0.05	0.83	18	0.13	0.59	18	0.16	0.51

DAP: dose area product.

BMI: Body mass index.

n = Number of patients included in the analysis.

r = correlation coefficient.

P = significant level.

Table 5 outlines the radiation-related lifetime cancer risk as a function of age at exposure and sex. As seen, the radiation-related lifetime cancer risk in lumbar spine and abdominal x-ray are the highest per million exposures. The increase in radiation-related lifetime cancer risk in patients with obesity can reach up to 152% increase especially in younger patients compared to patients with normal-weight.

Discussion

The study aimed to evaluate the radiation DAP delivered to patients with obesity in projection radiography and explored the relationship between DAP and patient anthropometrics. The projected radiation-related lifetime cancer risk in patients with obesity was estimated and compared to adult patients with normal-weight, based on the latest NDRL review 2010 [2]. For the five procedures reported in this study; abdomen (AP), lumbar spine (AP + LAT), chest (PA), pelvis (AP) and cervical spine (AP + LAT), patients with obesity received higher DAPs, compared to the NDRL values for these procedures. The highest DAP was reported in abdominal (AP) and lumbar spine (AP + LAT) radiographs (17.6 and 30.31 Gy cm²) respectively. This is of concern as these two examinations comprise 3.81% and 2.53% of the x-ray examinations conducted in the UK out of 231 types of examinations [38]. Whole dose are lower when compared with CT, which contributes to 47% of the medical radiation dose within the UK population, while projection radiography still contributes 34% [39]. However, when considering the high prevalence of obesity in the UK, the large number of patients with obesity presenting for radiographic assessments due to obesity related comorbidities along with difficult clinical assessment and the high percentage of these two procedures, the collective and cumulative dose will be of concern. Moreover, the most sensitive organs such as colon and stomach are in the direct beam of radiation in these two procedures, while the remaining sensitive tissue such as lungs and breast are in the near field of scattered radiation. The DAPs of pelvis (AP) is not as high as in the case of abdomen and lumbar spine radiographs. This is counterintuitive, however, this could be attributed to the small number of 27 patients included in this study. Radiographers are facing tremendous challenges when imaging patients with obesity as the data indicates the weight of patients with obesity can reach up to 300 kg. The weak to fairly moderate correlations between the DAP and patient's size in abdomen and chest procedures indicate that high DAPs are delivered to lower BMI patients within the cohort and vice versa. This could be attributed to the absence of clear guidelines in the literature to help achieve an optimal image with the lowest practicable dose [40]. Such variation has already been reported in selection of exposure factors, which impact directly on DAP, for patients with obesity [41]. However, the local DRL for the reported investigations in this study is lower by 32% on average than NDRL. This indicates good protocols already in place to ensure adherence with the ALARP principle. As a result, the reported DAPs for patients with obesity could be at the lower band of radiation dose (DAP) to this group of patients as the local DRL evident the good practice in place. Additionally, as a bariatric centre, the staff are highly trained to x-ray patients with obesity. The increase in the radiation-related lifetime cancer risk incidence is an indication of new challenges in the health management of patients with obesity. Due to the semi-identical median DAP for both groups in cervical spine AP & LAT projections, the absorbed dose in the obese group was less than NDRL group. This eventually impacts on the cancer risk estimation which shows a decrease in radiation-related lifetime cancer risk in obese group compared to the DRL group. This could be explained by the fact that the absorbed dose in patients with obesity less than the normal-weight adult when receiving identical DAPs, due to the extra fat which acts as a

Table 5. Radiation-related lifetime cancer risk incidence for both groups of patients (per 10⁶).

Age		Abdomen (AP)		Chest (PA)		Pelvis (AP)		Lumbar spine (AP)		Lumbar spine (LAT)		Lumbar spine (AP + LAT)		Cervical spine (AP)		Cervical spine (LAT)		Cervical spine (AP + LAT)	
		Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
20–29	DRL	21.8	20.5	0.7	1.3	14.2	11.1	24.8	23.1	14.7	12.5	39.4	35.6	0.7	1.3	0.7	0.9	1.4	2.2
	Obese	55.1	51.9	0.9	1.5	15.4	12.0	41.9	36.2	29.1	24.5	71.0	60.7	0.7	1.2	0.6	0.9	1.4	2.0
	Δ%	152.6	153.1	33.7	16.6	9.1	8.3	69.0	56.8	98.5	95.5	80.0	70.4	4.4	-5.9	-5.7	-6.4	-0.5	-6.1
30–39	DRL	17.4	16.4	0.6	1.2	11.6	9.1	19.7	18.3	11.6	9.7	31.3	28.0	0.5	0.8	0.5	0.6	1.0	1.4
	Obese	44.1	41.4	0.8	1.4	12.6	9.8	33.6	29.2	23.0	19.2	56.6	48.3	0.5	0.7	0.5	0.6	1.0	1.3
	Δ%	153.1	152.4	29.9	16.7	9.0	8.7	70.4	59.2	99.1	97.5	81.0	72.5	4.2	-4.2	-4.7	-4.0	-0.1	-4.1
40–49	DRL	13.5	13.2	0.6	1.2	9.2	7.6	15.2	14.4	8.9	8.1	24.2	22.5	0.4	0.5	0.3	0.4	0.7	0.9
	Obese	34.2	33.1	0.8	1.4	10.1	8.2	26.3	23.4	17.8	16.1	44.0	39.5	0.4	0.5	0.3	0.4	0.7	0.9
	Δ%	153.2	149.9	26.9	17.8	8.9	8.1	72.3	62.4	99.4	99.6	82.3	75.7	4.4	-3.2	-3.0	-0.8	0.8	-2.2
50–59	DRL	9.8	9.9	0.6	1.1	6.8	5.7	10.9	10.6	6.3	5.6	17.3	16.2	0.3	0.3	0.2	0.2	0.5	0.6
	Obese	24.7	24.7	0.7	1.3	7.4	6.2	19.0	17.7	12.7	11.5	31.8	29.2	0.3	0.3	0.2	0.3	0.5	0.6
	Δ%	153.2	149.1	24.5	17.3	8.9	9.3	74.6	66.9	100.4	104.4	84.1	79.9	1.6	-3.2	-1.7	3.6	0.0	-0.2
60–69	DRL	6.2	6.7	0.4	0.8	4.3	3.9	6.8	7.1	3.9	3.5	10.7	10.6	0.2	0.2	0.1	0.2	0.3	0.4
	Obese	15.5	16.7	0.5	1.0	4.7	4.3	11.9	12.3	8.0	7.3	19.9	19.6	0.2	0.2	0.1	0.2	0.3	0.4
	Δ%	151.5	148.0	22.6	17.0	8.9	10.5	76.4	72.2	102.0	109.0	85.8	84.3	0.5	-6.2	1.1	6.8	0.8	-0.7
70–79	DRL	3.2	3.7	0.3	0.5	2.2	2.1	3.4	3.9	2.1	1.8	5.5	5.7	0.1	0.1	0.1	0.1	0.2	0.2
	Obese	8.0	9.2	0.3	0.6	2.4	2.4	6.1	6.9	4.2	3.9	10.3	10.8	0.1	0.1	0.1	0.1	0.2	0.2
	Δ%	148.1	144.1	21.7	17.2	8.3	11.7	76.9	77.2	102.9	114.7	56.6	89.2	-4	-9.0	3.1	10.4	-0.8	-1.0
80–89	DRL	1.1	1.3	0.1	0.2	0.7	0.7	1.1	1.4	0.8	0.6	1.9	2.0	0.0	0.0	0.0	0.0	0.1	0.1
	Obese	2.7	3.1	0.2	0.2	0.8	0.8	2.0	2.4	1.6	1.3	3.6	3.8	0.0	0.0	0.0	0.0	0.1	0.1
	Δ%	138.9	138.3	21.8	17.5	7.0	11.5	77.5	80.3	104.0	114.0	88.2	90.8	-8.6	-13.8	4.0	10.1	-3.0	-4.2

DRL = Diagnostic Reference Level.

AP: Anteroposterior.

PA: Posteroanterior.

LAT: Lateral.

Δ%: difference percentage.

protection layer for the internal organs. The reported radiation-related lifetime cancer risk in this study is a projected risk and did not take into account any other factors or background cancer rates. Additionally, it does not consider the issue of obese patients may receive more diagnostic radiography procedures but rather consider the single exposure reported in this study. This is due to the uncertainty in the model used to calculate the risk. Although, obesity is already reported to increase the risk of different types of rare cancers [20], however, the projected radiation-related lifetime cancer risk reported in this study is applied only on this cohort group based on the reported DAP of the specific radiographic investigations. Hence, the radiation-related lifetime cancer risk to the whole obese populations has not been considered as the data were collected from one centre. Likewise, the same applies to the normal-weight group, as the projected radiation-related lifetime cancer risk is for the patients who received identical DAP dose reported in the NDRL, which does not necessarily applies to all patients with normal weight due to the variation of local DRLs across the country.

This study is the first study to report the radiation dose (DAP) delivered to patients with obesity in projection radiography and to calculate effective risk for this group of patients. Yanch and colleagues have reported similar results of high effective dose delivered to patients with obesity but these were based on Monte Carlo simulation [42]. They utilised layers of fat added to the computer based stylised phantom in five different orientations, which do not necessarily reflect actual patients shape. Also they did not base the simulation on radiation dose data, either entrance surface dose or DAP, reported in clinical practice, which does not reflect radiographers' practice in clinical context.

Despite that, the current study should be interpreted in the context of its limitations. As a retrospective study, restrictions were unavoidably placed on the exclusion criteria. For example, DAP readings are usually entered by the radiographer for multiple views or even multiple examinations, if conducted at the same time. As a result, inclusion of such patients was not possible as the DAP is not representative of the view and exam of interest. This means the DAPs could be higher than the values reported in the study. The opposite could also be true as the DAP readings jeopardise of typos entry mistakes by the radiographers at the time of the exam. As the study was conducted retrospectively, one of its limitations is the lack of the examined anatomy thickness data, which of course could vary for the same BMI group patients.

Another limitation of the study is the use of PCXMC 2.0 to estimate mean organ absorbed dose. This is attributed to the fact that the PCXMC phantom does not take into account the changed morphology and fat distribution in organs of patients with obesity, this impacts on the accuracy of the estimated absorbed dose. However, to date there is no accessible computerised voxel phantom, representative of high BMI similar to the mean BMI of the participants in the current study, in order to use other Monte Carlo as an alternative for more realistic absorbed dose estimation. Additionally, the accuracy of the estimated radiation-related lifetime cancer risk limited by the uncertainties of the BEIR II model, used in this study, which is based on the life-span studies of atomic bomb survivors and the risk coefficient, which is statistical averages over many individuals of the same gender and similar age. Hence, caution must be taken when interpreting the results individual radiation-related lifetime cancer risk. Nevertheless, the results provide a valid starting point for future research on this topic.

The study shows a new potential challenge in patients with obesity' management in radiology departments specifically, with serious implications for the health service in general. DAP variations demonstrate the need for clear and accessible guidelines of obese patient's management in radiology departments. Additionally, the study highlights the increases likelihood of cancers to be seen among patients with obesity who undergo such

investigations. Therefore, extra work on dose optimisation is required and guidelines need to be in place to assist the radiographers in imaging these patients. Clinician could use the results of the current study when communicating the benefit and risk of such investigation.

Several aspects of the study results warrant further studies. Our study considered patients with obesity, but the BMI range was 40 kg m^{-2} and over. This is mainly because the data were sourced from a bariatric surgery where patients' BMI tends to be 40 kg m^{-2} and above, in accordance with the national institute for health and care excellence [43]. Hence, the patients with obesity ranged from 30 to 40 kg m^{-2} , which possibly account for a relatively large group of people, were not reported. This was not possible as such data are not usually collected for the projection radiography procedures in the site where this study is conducted. A future prospective study where patient's height and weight are measured before the exam could be conducted to evaluate the DAP for the group of patients with BMI between 30 and 40 kg m^{-2} . Additionally, further studies could be conducted to determine the factors that impact on DAP such as radiographer's experiences and type of x-ray machine.

Conclusions

The findings of the current study may have implications for clinicians, radiographers, policy makers and health economists. Clinicians should re-consider the radiation-related cancer risk when justifying x-ray procedure for patients with obesity, which is different to patient with normal-weight. Radiographers could specifically evaluate the DAP to patients with obesity periodically. Additionally, daily monitoring of imaging this group of patients and recording the level of obesity and the exposure factors used could help in tackling this issue through the auditing. Policy makers considering improving the quality of health services could take this result into account and negotiate with health technology manufacturers to find ways to tackle the high dose delivered to patients with obesity. For health economists, this could be taken into account when estimating the economic burden as a result of obesity. Additionally, research is needed in dose optimisation for patients with obesity to establish appropriate exposure guidelines.

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Conflict of interest

None

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