Kaunas University of Technology

Faculty of Mathematics and Natural Sciences

Setting of Local Dose Reference Levels at Kaunas Republican Hospital

Master's Final Degree Project

Timūr Jariomenko

Project author

Prof. Diana Adlienė

Supervisor

Nikolajus Medvedevas

Co-supervisor

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Doc. Dr. Jurgita Čyvienė

Reviewer

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Declaration of Academic Integrity

I confirm that the final project of mine, Timūr Jariomenko, on the topic „Setting of Local Dose Reference Levels at Kaunas Republican Hospital“ is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

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Jariomenko Timūr. Setting of Local Dose Reference Levels at Kaunas Republican Hospital. / Master's Final Degree Project/supervisor prof. Diana Adlienė, Faculty of Mathematics and Natural Sciences Kaunas University of Technology / co-supervisor Nikolajus Medvedevas; Kaunas Republican Hospital

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Summary

Measurements of patient‘s exposure during X-ray examinations using TLD have been replaced by two other methods: dose evaluation using exposure parameters and dose recalculation from dose-area-product (DAP)-meter values. Standard patients (70±5 kg) are usually taken into account when setting dose reference levels and it is recommended to keep patients exposure not higher than the level of DRL. However, the majority of patients are not standard. Performed investigation which was conducted exploring applying both new methods for dose evaluation has shown that it is very important to include the data of non-standard patients when setting local dose reference levels.

Analysis of biometric data of patients examined at the Republican Hospital of Kaunas has revealed that the average weight of patients was 82.9 kg, however, varied in the broad interval of weights. The comparison of dose data for standard and non-standard patients collected for *in situ* examined patients in 2 most common X-ray exams with 40 patients per exam has disclosed the importance for the inclusion of all patients when evaluating dose reference values

Also, data from patients DICOM files for 8 most common X-ray exams at the hospital was investigated retrospectively. A sample of 200 patients per exam was analyzed. Calculated exposure doses for non- standard patients were similar to those evaluated in an *in situ* survey. The results of the investigation (DAP values) were compared to the national Diagnostic reference levels of Lithuania and a new local DRLs were proposed.

Jariomenko Timūr. Diagnostinių atskaitos lygių nustatymas Respublikinėje Kauno ligoninėje. Magistro medicinos fizikos studijų baigiamasis projektas / vadovė prof. Diana Adlienė, Kauno technologijos universitetas, Matematikos ir gamtos mokslų fakultetas / konsultantas Nikolajus Medvedevas, Respunlikinė Kauno ligoninė.

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Santrauka

Paciento apšvitos dozės matavimai rentgeno tyrimų metu naudojant TLD buvo pakeisti dviem kitais metodais: dozės vertinimu naudojant ekspozicijos parametrus ir dozės perskaičiavimas pagal dozės-ploto (DAP) matuoklio vertes. Nustatant atskaitinius dozės lygius paprastai vertinami standartiniai pacientai (70 ± 5 kg), todėl rekomenduojama, kad pacientų ekspozicija neviršytų DAL lygio. Tačiau dauguma pacientų nėra standartiniai. Atliktas tyrimas, kurio metu buvo naudojami abu naujai pasiūlyti dozės įvertinimo metodai, parodė, kad nustatant vietinius (ligoninės) dozės atskaitos lygius, labai svarbu įtraukti duomenis apie nestandartinius pacientus.

Išanalizavus Kauno Respublikinėje ligoninėje tirtų pacientų biometrinius duomenis paaiškėjo, kad vidutinis pacientų svoris buvo 82,9 kg, tačiau kito plačiame svorių intervale. Palyginus standartinių ir nestandartinių pacientų dozių duomenis, surinktus *in situ* pacientams atliekant 2 dažniausius rentgeno tyrimus, su 40 pacientų viename tyrime, paaiškėjo, kad nustatant dozės atskatos lygius, svarbu įvertinti visus pacientus.

Taip pat buvo retrospektyviai išanalizuoti pacientų DICOM bylų duomenys susiję su 8 dažniausiais rentgeno tyrimais ligoninėje. Kiekvieno tyrimo atveju buvo analizuojami 200 pacientų duomenys. Suskaičiuotos ekspozicijos dozės nestandartiniams pacientams buvo panašios į tas, kurios buvo įvertintos *in situ* tyrimo metu. Tyrimo rezultatai (DAP vertės) buvo palyginti su Lietuvos nacionaliniais diagnostiniais atskaitos lygiais ir pasiūlyta naujos vietinės ligoninės DAL.

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Abbreviations:

DRL – Diagnostic reference level;

DAP. – Dose area product;

ESD. – Entrance surface dose;

DICOM – Digital Imaging and Communications in Medicine;

PACS – Picture archiving and communication system;

AP – Anterior-posterior;

LAT – Lateral;

PMMA – Poly(methyl methacrylate);

TLD – Thermoluminescent dosimeter.

Introduction

With the advancement of technology, medicine without procedures that uses ionizing radiation is no longer conceivable. The use of ionizing radiation brings enormous benefits to the diagnosis and treatment of illness. However, before handling procedures involving ionizing radiation, possible harm to the patient should be considered, i.e. medical exposure of patients during radiation treatment and diagnostic procedures should be taken into account.

One of the ways to control the patient's exposure during X-ray diagnostic procedures is patient dosimetry. Health care institutions are required to evaluate the dose to the patient received during X-ray diagnostic procedures. A physician is usually responsible for the medical exposure of patients, but medical physicists should be involved in assessing the radiation dose received by the patients and optimizing it to secure radiation protection and safety of the patient. Dose assessment is performed by registering the patient data, date of the performed procedure, type of the performed measurements, and calculations of dose including its comparison with the established diagnostic reference levels. In addition, the optimization of X-ray diagnostic procedures requires an additional assessment of the quality of these procedures. The established diagnostic reference levels help detect misconceptions and optimize existing ones [1].

The aim of the work was: to establish local diagnostic reference levels for X-ray procedures at the Republican Hospital of Kaunas.

To achieve this goal following tasks were set:

1. Evaluate the reliability of DAP readings for the patient’s dose assessment.
2. Analyze biometric data of real patients undergoing certain diagnostic procedures and compare doses to a standard and non-standard patients.
3. Examine DICOM images of patients and establish local diagnostic reference levels for a certain X-ray diagnostic procedures.

1. Literature analysis

The diagnostic reference level (hereinafter referred to as "DRL") is described as the dose level used in a standard study in a group of standardized patients. According to the definition given in Council Directive 2013/59 / Euratom, the diagnostic reference levels are the dose levels used in medical radiation diagnostics or interventional radiology, or in the case of radiopharmaceuticals, the levels of activity established for the widely used types of equipment used in standard-size patients or standard-sized phantoms. Determining the dose level for X-ray diagnostics that delineates the boundary between "good" and "bad" medical practice is very complicated and sometimes impossible, and therefore DRL is used to optimize medical exposure. When performing standard X-ray diagnostic and interventional radiology procedures (hereafter referred to as procedures), DRL is not expected to be exceeded in daily practice, especially if the hospitals work through best practice.

With the advancement of digital radiography and network, a new technique was proposed by researchers for establishing DRL's, with the use of the PACS system and DICOM imaging format an online automatic diagnostic reference level management system was created solely by extracting DICOM image code lines from the PACS system [2].

Radiation doses in X-ray were also estimated using DICOM information in a study by Suliman et al. in a large hospital by recording the DICOM data for 547 patients for most common X-ray exams [3]. A somewhat similar approach was used in this work.

DRL's have received some criticism in recent articles whether they are suitable anymore for use today. Sutton et al. calls into question the usage of DRL's in the modern world once a certain degree of optimization has taken place. In that study, he states that doses are not following a distribution keeping with the current concept of DRL's [4].

The author has also found support by Rehani et al. where he even proposed a new term "Acceptable Quality Dose (AQD)" where he recommends each facility to determine averaged dose values (±standard deviation) for each examination that has images of clinically acceptable quality for physicians and are graded in weight groups of 10 kg for adults e.g. 61 – 70, 71 – 80, 81 – 90 and so on. For children, he suggests to categorize them in 5 kg weight slots. He believes that AQD could serve as a "standard dose" and could be compared with AQD in another room or facility. AQD could be used in adjusting parameters whose estimated dose value is likely to exceed AQD ±standard deviation [5].

A somewhat similar approach was used in another study where patients were categorized by their body mass index (BMI) values into three categories: normal (18.5–24.99 kg/m2), overweight (25–29.99 kg/m2) and obese (>30 kg/m2). Patient weight, height, and thickness of the examined anatomical region was recorded. Patient's kerma area product (KAP) values were recorded, and the entrance surface air kerma (ESAK) was calculated based on the X-ray tube output, exposure parameters, and technical data. Local diagnostic reference levels were established in that study with three BMI categories for each exam. The results of the study can be seen in Table 1 [6].

Table 1 Local DRL's set by patients BMI [6]

Examination	LDRL's		Examination	LDRL's	
	KAP (Gy·cm^2)	ESAK (mGy)		KAP (Gy·cm^2)	ESAK (mGy)
Chest PA			**Lumbar AP**		
Normal	0.08	0.11	Normal	0.98	3.76
Overweight	0.13	0.17	Overweight	2.10	7.70
Obese	0.21	0.28	Obese	4.01	15.10
Chest LAT			**Lumbar LAT**		
Normal	0.39	0.74	Normal	1.41	4.47
Overweight	0.69	1.21	Overweight	2.59	7.99
Obese	1.10	1.82	Obese	4.80	13.86
Abdomen AP			**Pelvis AP**		
Normal	1.23	1.86	Normal	1.23	2.28
Overweight	2.35	3.74	Overweight	2.13	4.07
Obese	4.68	7.26	Obese	3.27	6.89

The same authors performed another study recording exposure doses with low BMI for the same X-ray examination projections. The results were 74 – 90% lower compared to the national Greek DRL's, 35 – 84%, and 58 – 82% compared to the UK DRL's [7].

1.1. Diagnostic reference levels in the world

The ever-growing demand for X-ray examinations by physicians has led to a massive increase in the X-ray examinations per capita in the world. There is evidence of an increasing ionizing radiation dose to the population from diagnostic imaging procedures [8]. Dose optimization is of growing importance and can be met through a concept of diagnostic reference levels (DRL's) for standardized procedures. Studies have been carried out in many countries to determine the national or local diagnostic reference levels.

DRL's are usually set for the most popular radiographic procedures in anterior-posterior (AP), posterior-interior (PA) and lateral (LAT) projections. Mostly used protocols include: chest, abdomen, pelvis, hip, cervical spine, thoracic spine, and lumbar spine. However, some countries like Belgium established their DRL's only for very few protocols (Chest PA, abdomen AP and pelvis AP) [9].

A study in Iran carried out in 2016 [10] was focused on spine examinations only: cervical AP; cervical LAT; thoracic AP; thoracic LAT; lumbar AP; lumbar LAT.

National studies performed in Austria (2018) [11] and in the Netherlands (2016) [12] were focused on the establishment of diagnostic reference levels for 12 anatomical examinations in Austria and 11 in the Netherlands.

A local study in Italy determined entrance skin dose (ESD) for 10 standard projections (AP Abdomen, PA and LAT Chest, AP and LAT Lumbar Spine, LAT Lumbo-Sacral Joint, AP Pelvis, PA and LAT Skull and AP Urinary tract) [13].

Not all countries even have their own national DRL's, only more developed countries [14] can afford to have their own DRL's while less developed countries with a high amount of radiological equipment don't have their national DRL's although work has been carried out to establish national DRL's. [15, 16].

There were some difficulties in attaining all the required data for establishing DRL's. In an Austrian study, only 59% of all medical facilities participating in the study were able to provide the dose area product values for X-ray examinations. And not all of them provided all the required data for research. For instance, only 43% of participating medical facilities provided data on the patient's weight. Nevertheless, the conclusions of the study were drawn even knowing that some data is missing.[11].

Studies have shown an overall decrease of DRL's through time due to better equipment and routinely performed quality control during procedures [17, 18]. In Europe DAP values are mostly used, though in countries like Canada an entrance surface doses (ESD) are used for the establishment of national DRL. Different from European countries Canada is using a range of diagnostic reference doses rather than strict limits. Another note from Canada is that established DRL's are dependent on radiography equipment, one for the computed radiography and another one – for digital radiography. Digital radiography tends to have lower DRL [9].

Most countries set their DRL's at the third quartile (75^{th} percentile) level from the performed dose surveys, while, in the United States DRL's are set by the American Association of Physicists in Medicine at 80^{th} percentile level of the survey distributions [19].

Table 2 Comparison of national and local DRL's in Canada [19]

Examination	**Digital Radiography**	**Computed Radiography**	**National DRL's mGy**
	Local DRL's, mGy	Local DRL's mGy	
Chest PA	0.09	1.1	0.2-0.3
Chest LAT	0.4	3.5	0.7-1.5
Lumbar-spine AP	4.1	10.8	7-10
Lumbar-spine LAT	8.9	29.0	15-30
Abdomen AP	4.8	5.3	7-15
Pelvis AP	2.9	3.7	5-10

DRLs for different anatomic regions that were established using DAP values in different European countries are provided for the comparison in Table 3.

Table 3 Comparision of radiography DRL/75th at percentiles level in different European countries [9, 20]

Examination type	DAP (cGy·cm^2)					
	Switzerland (2011)	UK (2012)	Germany (2016)	Belgium (2016)	France (2017)	Lithuania (2018)
Chest (PA)	15	10	15	30	25	20
Chest (LAT)	60	-	40	-	100	30
Abdomen	-	250	230	275	700	250
Pelvis (AP)	250	220	250	350	700	300
Hip (AP or LAT)	-	15	-	-	300	-
Cervical spine (AP or LAT)	-	15	-	-	75	-
Thoracic spine (AP)	-	100	110	-	175	160
Thoracic spine (LAT)	-	150	140	-	275	220
Lumbar spine (AP)	235	150	200	-	450	150
Lumbar spine (LAT)	415	250	350	-	800	500

It is worth noting that in Lithuania compared to 2011 the newest DRL's that were adopted in 2018 were somewhat similar to earlier versions with the difference in the Thoracic spine exam and Hip exams that were set lower. For 2011 TH AP was set at 3 Gy·cm^2 while in 2018 revision it was lowered to 1.6 Gy·cm^2. For TH LAT in 2011, it was set at 4 Gy·cm^2 while in 2018 it was revised to 2.2 Gy·cm^2. For Hip joint exam the DRL was changed from 1.6 Gy·cm^2 to 1.4 Gy·cm^2 [20, 21].

A metastudy conducted during 2015 – 2017 in the EU has shown a high variability in DRL's in different countries ranging from 30% to 200% depending on the data collected from DAP devices. Though the more data was collected the smaller the variability of doses was achieved. Usually, it stabilized at 30% when the number of DAP data was higher than 200 per one DAP device [22].

Local diagnostic reference levels are not very common in the world. Though there is an ongoing work for the establishment of local DRL's [23, 24, 25, 26]. A survey in the Netherlands conducted in 2016 confirmed that most hospitals don't have their local diagnostic reference levels [27]. It was also shown that the awareness of and use of diagnostic reference levels are not appropriate in radiology departments of hospitals. Interesting results were obtained in a pan-European survey which was conducted to check the knowledge of radiology department staff whether they use or know about diagnostic reference levels and results are shown in Figure 1.

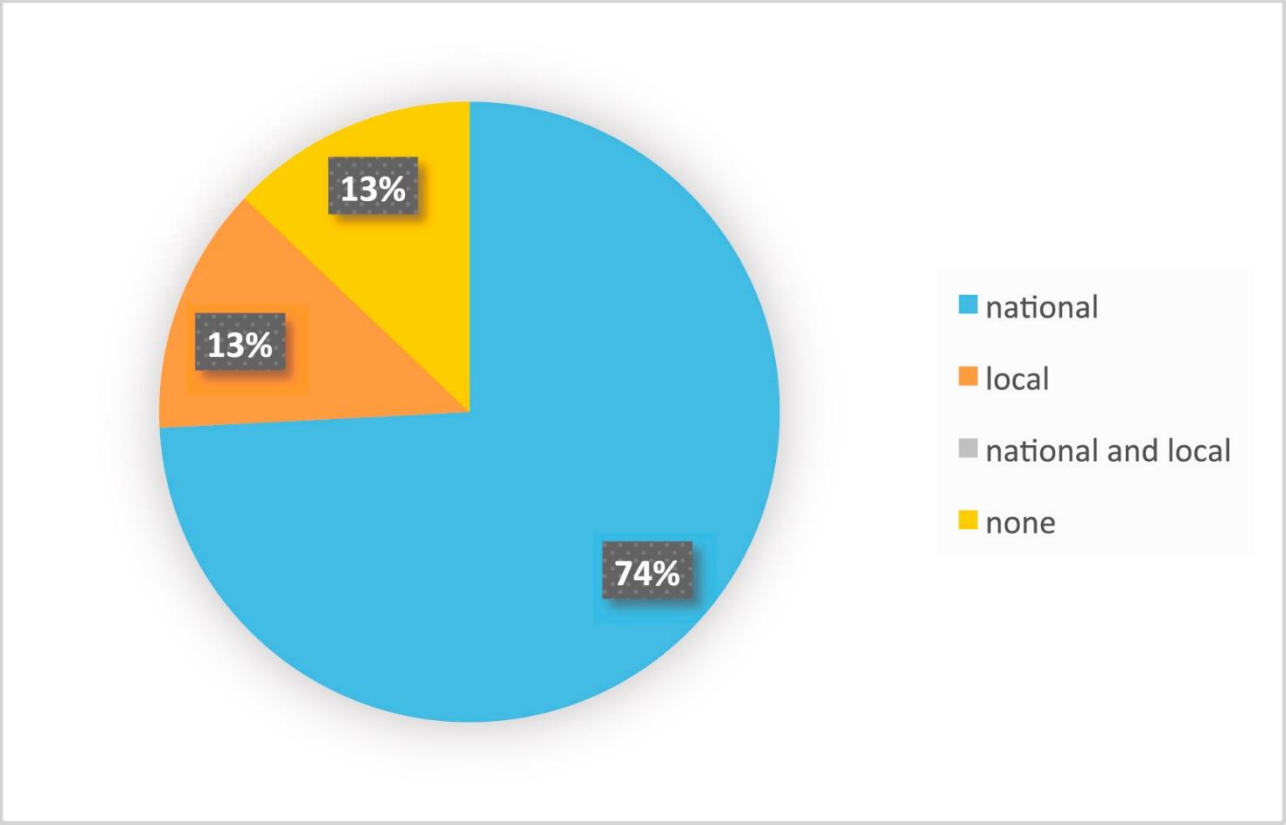

Fig. 1 Awareness of DRL in the European imaging departments [27]

To the survey question regarding the awareness of the use of DRL in their departments 74% of respondents answered that they were using nationally established DRL, 13% using LDRL, and 13% – reported they do not have DRLs [27].

The individual patient's exposure doses are not comparable with DRL, because the exposure dose depends on the individual patient's characteristics. One patient's higher exposure dose during the procedure may be reasonable and the procedure is considered to be optimized. DRLs are set at the national level, and it is recommended that they be set at the local level, i.e. at the same hospital [28].

2. Establishment of dose reference levels

In Lithuania, the periodicity of the assessment of exposure to radiation in patients during procedures is determined in the Hygiene Norm HN 73: 2001 "Basic Radiation Safety Standards" and Hygiene Norm HN 31: 2008 "Radiation Safety Requirements in Medical X-ray Diagnostics". By these hygiene norms, the hospitals must assess at least 10 standard patient groups and evaluate the average dose received during procedures once every five years.

Taking into account the international recommendations patients should receive an estimation of exposure doses every year and the exposure should be optimal. However in many cases, a different number of different X-ray diagnostic procedures at different hospitals could be performed for the same patient during a year, so the patient exposure doses in all hospitals during procedures are not optimal over the same period. It is recommended that a plan is drawn up that assesses the patient exposure doses for every five years in all procedures performed in the hospitals so the same exposure dose level every year is hardly achievable. Due to this, it was agreed to evaluate average annual doses from doses received by patients from all X-ray examinations within five years period.

This request revision of national DRL's every five years taking into account that installation of medical equipment, software, and imaging modalities and other means allows for optimization of exposure doses to patients over time.

2.1. Patient selection criteria

Choosing appropriate X-ray diagnostic apparatus in the procedure depends on the patient's physical data: weight and scanned area thickness and length. A larger person receives a higher dose of radiation in order to obtain a picture of a better quality than a lighter person. Therefore, the DRL is set to 70 ± 10 kg for a patient weighing a standard weight. There are two ways of selecting patients to assess the average dose rate received during procedures. If patients are evaluated for standardized patient-to-patients exposure, the sample size should be at least 20 patients per procedure [28]. For large-scale studies, patients weight limits may be increased to 70 ± 20 kg, but then the sample size must be at least 200 patients per procedure. The average weight of the whole sample must be 70 ± 5 kg.

2.2. Exposure doses received by patients

The radiation doses received by patients in radiographic procedures can be evaluated in two ways:

1. Calculating the dose on the entrance surface (Surface entrance dose, ESD)
2. Measuring the value of the dose and area of the product with the dose and area product meter (DAP)

Parameters are recorded for the evaluation of the exposure doses received by patients. The purpose of patient exposure doses is to make sure that the average patient exposure dose does not exceed the DRL in the procedures performed, and that this dose and the quality of the resulting image are optimal. Therefore, in assessing the radiation doses received by patients, the technical parameters of the X-ray diagnostic apparatus must be recorded, on which the radiation dose and the quality of the received image are based on the patients. Some technical parameters are recorded, some are measured, and some are calculated using formulas. The following are a brief description of the main

parameters of the X-ray diagnostic apparatus and their influence on the dose rate received by patients, as well as the diagnostic image quality:

1. **Voltage** - the energy of X-ray radiation is described by the anodic voltage of the X-ray tube. The higher the voltage, the more radiant the X-ray is. From the anode voltage, the contrast of the image depends on the higher voltage, the higher the voltage the worse is contrast. The X-ray spectrum is continuous, increasing the anode voltage by increasing the amount of low-energy X-rays [29].

Radiation of photons that do not have the ability to pass through the human body and reach the detector - they are absorbed by human tissue (increasing the patient's exposure) but are not used to obtain a diagnostic image. Therefore, X-ray diagnostic equipment always uses filters that filter out lower-energy X-ray photons. In mammography, it is particularly important that the combination of the anode (target) and the filter material is appropriate, since the diagnostic images are obtained using a low-energy characteristic anode spectrum, which uses the filter as weak as possible. If the filter absorbs X-rays of useful energy, you will need to increase the anode current (increase the patient's exposure dose) to obtain a good diagnostic image [29].

2. **Current and time** - The measure of X-ray quantification is the current strength of the X-ray tube. The higher the current strength, the more intense the X-rays, and the detector records more X-ray photons. From there, the video noise decreases, reducing the current - the video noise increases (if other parameters are not changed). The amount of radiation received by the patient directly depends on the size of the current (doubling the current strength - doubling the patient's exposure dose). Time is also very important because it directly relates to the patient's exposure dose, the less the patient is exposed to, the less radiation dose. This parameter is very important in interventional radiology, where the duration depends very much on the doctor's experience and abilities. The anode voltage and current strength of the X-ray tube are closely related parameters in order to obtain a good diagnostic image: the voltage decreases - the current is increased and vice versa.

3. **Field size** - In the procedure of the patient, the area of exposure must be individually selected. The larger the area is irradiated, so the patient receives a higher exposure dose, so the larger area of the patient's surface should not be irradiated than necessary to diagnose. X-ray, X-ray mammogram, and interventional radiology procedures describe the area of irradiance as the concept of the irradiance field, which shows how large the surface area will be irradiated. In computer tomography, the area of irradiation is defined by the length of the scanned volume.

2.2.1. Dose output

The dose-output dependence on voltage should be known for the dose calculation at the surface level. The dose output is the kerma measured in air at a distance d which in this case is 1m (excluding scattered radiation) per unit of output per unit radiant tube current strength and exposure time (mA · s). Kerma is measured at a point d from the center axis of the X-ray beam at a distance d (in this case 1 m) between the x-ray tube and the detector, with the anodic voltages used in in the study ranged from 50 kV to 120 kV (every 5 kV). The radiation yield Y is calculated according to the formula below for the voltage used for each measurement:

$$Y(d) = \frac{(K_I \times d^2)}{(I_V \times t_V)}, mGy \cdot m^2 \cdot (mA \cdot s)^{-1} \quad (1)$$

K_I – measured dose (Kerma) value, d – the distance between the x-ray tube and detector, in meters; I_V – nominal value of current strength, in milliamps; t_V – nominal exposure duration, in seconds [30].

2.2.2. Dose area product

Newer X-ray diagnostic devices have an installed **dose area product** (DAP) meter, or if not, a portable DAP meter can be installed, which is connected with X-ray console and provides dose-area values obtained during each exposure. When assessing the exposure of patients using DAP values, data is collected and the average of DAP values, standard error, and comparison with the set DRL is calculated. This method of patient dose assessment is very simple and does not requires specific calculations. Correction of the displayed data is also possible:

$$DAP = DAP_R \times k \tag{2}$$

Where DAP is the calculated value of the dose and area of the product, mGy·cm^2, DAP_R - the displayed value of the DAP meter installed in the X-ray equipment, mGy·cm^2, k - the correction factor established during the measurement. Correction factor is determined as:

$$k = \frac{DAP_M}{DAP_R} \tag{3}$$

Where k is the correction factor, DAP_M is the measured value of the calibration DAP meter during the quality control, mGy·cm^2, DAP_R value is displayed in the X-ray equipment DAP meter, mGy·cm^2. [31]

2.2.3. Entrance surface doses

The Entrance Surface Dose (ESD) evaluates the total dose of the patient's irradiated skin surface. To calculate the ESD, in addition to the radiation output dependence on the anode voltage, the basic parameters of the performed X-ray procedure must be known: anode voltage (kV), current value and exposure time value of the product P_{It} (mA · s), the distance between the focal point and the patient's surface (m). With all data, the surface dose intake is calculated by:

1. Using the radiant output from the anode voltage curve or its equation and calculating Kerma on the patient's surface (KP, i), in mGy:

$$K_{P,i} = \frac{Y(d)P_{It}d^2}{d_{FSD}} = \frac{Y(d)Itd^2}{d_{FSD}} \tag{4}$$

   Y(d) – radiation output at a distance d, mGy · m2 · (mA · s) -1, I - current, mA, t - average exam time, seconds, d - the distance between the x-ray tube and the detector, m, d_{FSD} - the distance between the x-ray tube and the patient, m (it can be calculated from the distance (d) by deducting the patient's thickness).

2. Calculation of entrance surface dose (ESD), mGy:

$$ESD = K_{P,i} \times B \tag{5}$$

   $K_{P,\,i}$ – Kerma at patient's surface, mGy, B – coefficient of scattered radiation that can be found in „Radiation Protection, No 154 – European Guidance on Estimating Population

Doses from Medical X-Ray Procedures" [17].

2.3. Doses from Digital imaging

DICOM images of the real patients could be also used for the assessment of exposure doses to patients and for establishing the local diagnostic reference levels for certain X-ray diagnostic procedures.

DICOM (Digital Imaging and Communications in Medicine) is a medical industry standard for creating, storing, transmitting, and visualizing digital medical images and documents of examined patients.

DICOM is based on the OSI ISO standard and is supported by major manufacturers of medical equipment and medical software.

The DICOM standard was developed by the National Electrical Manufacturers Association. The standard covers the functions of creating, storing, transmitting and printing individual image frames, series of frames, patient information, research, equipment, facilities, medical personnel conducting the examination, and the like.

The DICOM standard defines two information levels:

- File-level - DICOM File - an object file with a tag organization for representing the image frame (or series of frames) and accompanying or control information (in the form of DICOM tags);
- Network-level - DICOM Network Protocols (network DICOM protocol) - for transmitting DICOM files and control DICOM commands over TCP / IP networks.

DICOM file - an object-oriented file with a tag organization, the information model of the DICOM standard for a DICOM file is four-step: patient → study → series → image (frame or a series of frames).

The file-level of the 2008 DICOM 3.0 standard describes:

- Patient demographic information;
- Model and company of the manufacturer of the apparatus on which the exam was performed;
- Attributes of the medical institution where the survey was conducted;
- Attributes of the personnel examining the patient;
- Type of examination and time;
- Conditions and parameters of the study of the patient;
- Image parameters or a series of images recorded in a DICOM file;
- Unique identification keys of the data groups described in the DICOM file.
- Image, series, or set of series obtained during examination of the patient.

- Representation, first of all, of PDF documents in a DICOM file.
- Presentation of DICOM-record on optical media, including DVD-format.

All DICOM images in modern hospitals go through a network called PACS. PACS (Picture Archiving and Communication System) - DICOM image transfer and archiving systems, suggest the creation of special remote archives on DICOM Server, where a very large amount of archived data can exist for a long time in a “hot” form and be quickly accessible for searching and viewing information of interest on the DICOM network.

3. Instruments and methods

3.1. Radiation output measurement

The experimental set up for radiation output measurements is provided in figure 2.

Fig. 2 X-ray machine radiation output measurement set up

X-ray unit Shimatzu RadSpeed Pro EDGE No. LM5249F5C006, 2015, X-ray tube 0.6/1.2P324DK-85 No. RM6D8585C008 was used for the performance of radiation output measurements. Unfors Multi-O-Meter 517 L was used to assess the dependence of radiation output on voltage. The detecting device was placed on the X-ray machine table in the center of the radiation field of 30 cm x 30 cm. Middle ion chamber was activated on the machine.

The distance between the focal spot and the detector was set at 100 cm. Anode voltage range was set between 50 and 125 kV. Anode current was set at 5.0 mA. The radiation output was measured using 5 keV steps. Figure 3 shows the good linearity of the radiation output dependence on the anodic voltage from the data of the experiment.

The dotted line shows the chosen voltage on the X-ray machine and the other line shows registered voltage with the multimeter device. The difference in the readings of multimeter and the X-ray machine is minimal and it shows the reliability of kV readings.

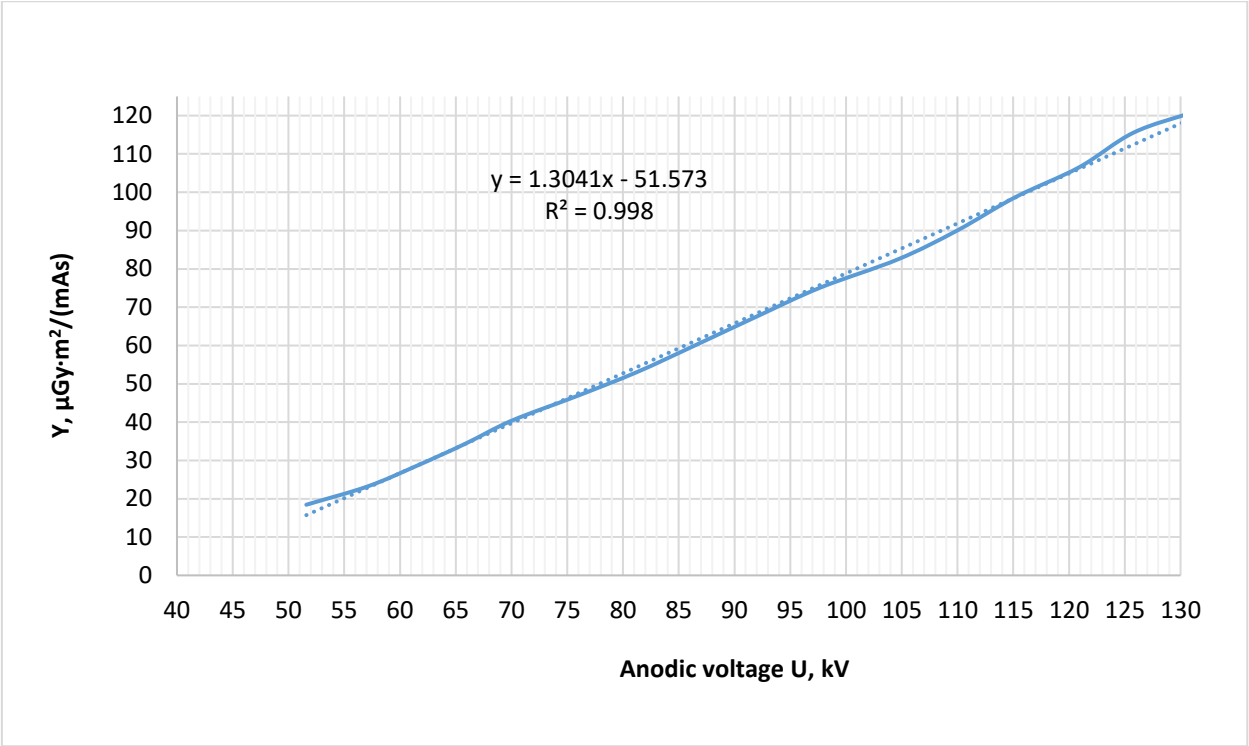

Fig. 3 Shimadzu RadSpeed Pro EDGE No. LM5249F5C006 dependence of radiation output on voltage.

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3.2. Calibration of TLD dosimeters

Linear dependence of radiation output on the anodic voltage allowed for dose calibration of LiF: Mg, Ti thermoluminescence dosimeters, provided by the Radiation Protection Center of Lithuania were calibrated with the known dose for further study. 20 TLD-100 dosimeters were calibrated and used for further measurements, taking into account, that groups of 4 dosimeters were exposed to the same dose for getting an average value.

On this stage, TL dosimeters provided by the Radiation Protection Center of Lithuania were calibrated with a known dose for further study. To have better dose measurements a further calibration of dosimeters was performed. 5 exposures with constant voltage and current were performed, only exposure time was changed. Exposure time was changed manually form 40 ms to 71 ms with the lowest possible steps on the X-ray machine console. TL dosimeter was placed in the radiation field together with the multimeter. After the exposure, the dosimeters were sent back to the Radiation Protection Center of Lithuania for scanning. The results for this calibration can be seen in Table 4 below with averaged dosimeter doses from 4 pills.

Table 4 Comparison of multimeter and TLD doses.

	1	**2**	**3**	**4**	**5**
Voltage, kV	100	100	100	100	100
Current, mA	100	100	100	100	100
Time, ms	40	50	56	63	71
Distance, cm	100	100	100	100	100
Average multimeter dose, µGy	334.2	416.6	469.2	525.8	593.6
Dosimeter dose, µGy	307	375	415	465	560

Multimeter values were consistently higher than dosimeter values. For 40 ms exposure it was 9% higher, for 50 ms it was 11% higher, for 56 ms it was 13% higher, for 63 ms it was also 13% higher, and for 71 ms it was 6% higher. The calculated coefficient between average multimeter and TLD values is 1.10.

3.3. Patient exposure assessment by entrance surface dose method

For the entrance surface dose measurements the X-ray machine parameters were set for the most popular chest X-ray procedure: 100 kV, 160 mA. Exposure time was set automatically. The diaphragm was left the same and a PMMA phantom was placed on the X-ray machine table to simulate a patient. The thickness of the phantom was 20.5 cm to represent a chest of a human so the irradiation field shrunk to 23.85 x 23.85 cm. 10 Exposures were performed and with each exposure dosimeter was placed in the middle of the field. Figure 4 below shows the experimental scheme.

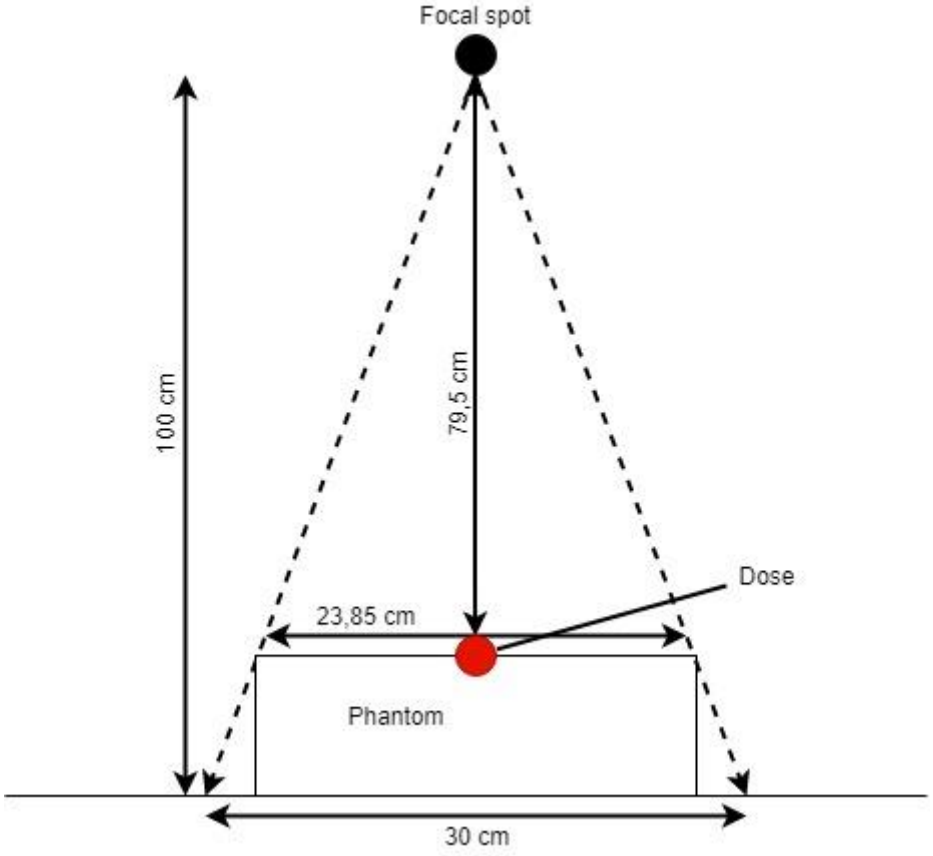

Fig. 4 Experimental scheme for ESD measurement

3.4. Patient exposure assessment by dose area product method

The experimental DAP values were obtained by two methods. In the first method, experimental dose and area product values were acquired by multiplying the X-ray field area on a simulated patient‘s body surface and kerma values, which were calculated from the radiation output curve while taking into account exposure parameters of the X-ray machine (anodic voltage (kVp), anode current (mA), exposure duration (ms)) and distance from the focal spot to patients surface (d=79.5cm). Figure 5 below shows an experiment scheme.

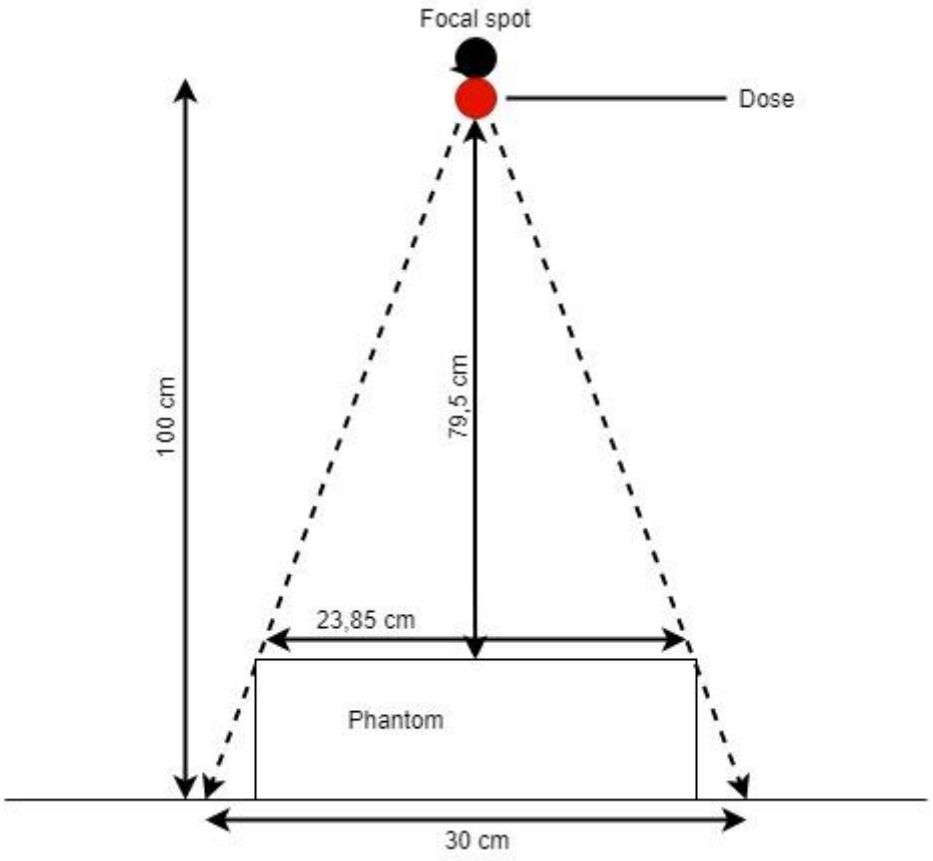

Fig. 5 Experimental scheme for DAP measurements

Using the second method, experimental dose and area product values were obtained by performing entrance surface dose measurements and multiplying the result with the X-ray field area on the patient‘s surface (DAP_{TLD}).

4. Results and discussion

4.1. Evaluation of the entrance dose

The entrance dose on the surface of the phantom was calculated using data obtained by performing measurements indicated in Figure 3 radiation output scheme.

After performing all exposures the TL dosimeters were sent to the Radiation Protection Center of Lithuania for reading.

Experimental data of this investigation is provided in Table 5 as well as a comparison of the entrance surface dose values evaluated theoretically and obtained experimentally are provided in Table 6.

Table 5 An ESD study

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Anodic voltage, kVp	100	100	100	100	100	100	100	100	100	100
Anode current, mA	160	160	160	160	160	160	160	160	160	160
Exposition time, ms	17	17	17	17	17	17	17	17	17	17
mA•s	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72
D_{100cm}[1], µGy	218.0	218.0	218.0	218.0	218.0	218.0	218.0	218.0	218.0	218.0
$D_{79.5cm}$[2], µGy	344.9	344.9	344.9	344.9	344.9	344.9	344.9	344.9	344.9	344.9
ESD[3], µGy	493.1	493.1	493.1	493.1	493.1	493.1	493.1	493.1	493.1	493.1
ESD_{TLD}[4], µGy	521.0	509.0	516.0	518.0	514.0	525.0	506.0	514.0	511.0	512.0

[1]Kerma is calculated based on the dependence of radiation output when the distance between the focal spot and the entrance point is equal to 100 cm.

[2]Kerma is calculated based on the dependence of radiation output when the distance between the focal spot and the entrance point is equal to 79.5 cm.

[3]Entrance surface dose is calculated by multiplying $D_{79.5cm}$ with scattered radiation coefficient B, which is equal to 1.43 at 100 kVp [17].

[4]Entrance surface dose is measured with TLD at the surface of the PMMA phantom.

Table 6 Calculated and measured doses

Evaluation method	**Mean ESD value, µGy**	***95 % confidence interval (ESD)***
ESD calculation	493.1	-
TLD measurement	514.6	±3.5

4.2. Evaluation of the dose area product value

The dose and area product values were displayed on the X-ray machine‘s control panel display after exposure. These values were calculated automatically using X-ray software based on radiation output curve and exposure parameters (anode voltage (kVp), anode current (mA), exposure duration (ms), X-ray field area on detector surface).

Experimental dose and area product values were obtained by two methods. In the first case, the dose and area product values were obtained by multiplying the X-ray field area on patient‘s body surface and kerma values, which were calculated from the radiation output curve, taking into account the exposure parameters of the X-ray apparatus (anodic voltage (kVp), anode current (mA), exposure duration (ms)) and distance from the focal point to the patient‘s surface (d=79.5 cm) (DAP_{calc}).

In the second case, the experimental dose and area product values were obtained by performing entrance surface dose measurements and multiplying the result with the X-ray field area on the patient‘s surface (DAP_{TLD}).

The results of the dose area product value evaluation by different methods are shown in Table 7 as well as the DAP values after averaging and calculating 95% confidence interval are provided in Table 8

Table 7 Comparison of DAP measurements

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Anodic voltage, kVp	100	100	100	100	100	100	100	100	100	100
Anode current, mA	160	160	160	160	160	160	160	160	160	160
Exposition time, ms	17	17	17	17	17	17	17	17	17	17
mA•s	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72	2.72
S^1, m^2	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057	0,057
$DAP_{theor}{}^2$, µGy•m^2	19.60	19.74	19.74	19.80	19.74	19.74	19.64	19.64	19.65	19.63
$DAP_{calc}{}^3$, µGy•m^2	19.62	19.62	19.62	19.62	19.62	19.62	19.62	19.62	19.62	19.62

DAP_{TLD}[4], µGy•m²	20.08	19.38	20.09	20.16	20.24	20.48	19.69	19.65	19.54	19.89

[1]Calculated irradiation field surface area on the PMMA phantom.

[2]Calculated dose from DAP readings on the X-ray machine console based on the surface area of the irradiation field.

[3]Dose is calculated based on the dependence of radiation output.

[4]Dose is measured with TLD at the surface of the PMMA phantom and multiplied by the surface area of the irradiation field.

Table 8 Experimental and theoretical DAP measurements

Evaluation method	**Mean DAP value, µGy•m²**	***95 % confidence interval (DAP)***
$DAP_{theoretical}$ (X-ray machine console readings)	19.69	±0.04
$DAP_{experimental}$ (based on the calculated kerma values from the radiation output curve)	19.62	-
$DAP_{experimental}$ (based on the dose values obtained from measurements from the TLD)	19.92	±0.31

X-ray machine console readings were quite persistent with low confidence interval range. While DAP measurements with TL dosimeters showed a somewhat higher range of measurements, though average results are quite similar.

The difference between averaged theoretical and experimental TLD measured DAP readings is 1.2%. It is an important note that considering the 95% confidence interval the range if TLD DAP measurements is from 19.61 to 20.23 µGy•m^2, so both DAP X-ray machine console readings and DAP calculated from the radiation output curve averages fall in that range.

The calculated coefficient between DAP readings on the X-ray machine console and TLD measured doses is k = 1.012, this coefficient k will be used further in this work to calculate more precise patient doses since data from X-ray machine will be used.

4.3. Reference dose levels and non-standard patients

4.3.1. Biometric data of the investigated patients

In the Republican Hospital of Kaunas, most common X-ray exams are Chest PA and Pelvis AP. Out of 40 pelvis examinations, only 11 patients were standard patient size. The rest of the patients were either lighter or heavier.

Out of 40 chest PA exam patients, only 14 patients could be considered as the standard patients and have a weight in the range of 65 to 75 kg.

The overall average weight of all patients was 82.9 kg, which is +13 kg from standard patient (70 kg). The weight of the lightest patient was 50 kg while of the heaviest patient - 140 kg

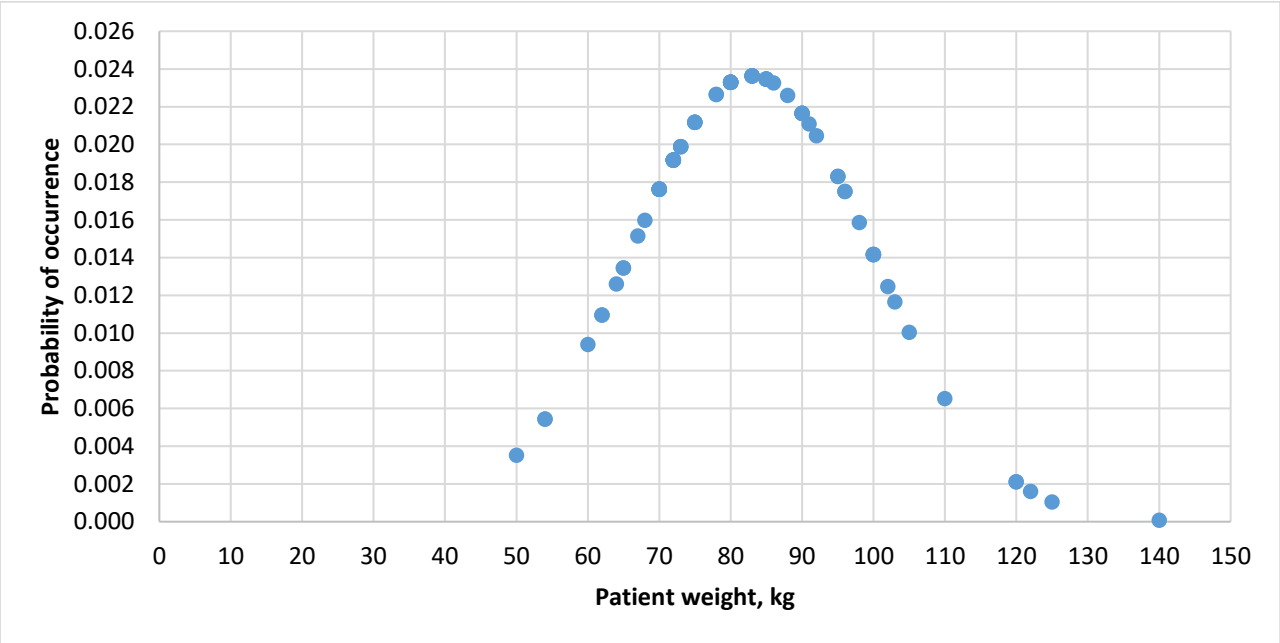

Fig. 6. Probability distribution of patient weight data

It is seen in figure 6 that patient weight distribution from the sample is slightly shifted to the right, which means that more patients have overweight as compared to the standard patient. The standard deviation for the sample is 16.8, which means a somewhat broad difference in patient weight.

Since patient age data is present in DICOM images, and the sample is much higher in DICOM images at 1600, it was extracted for analysis from there. As seen in figure 7, the most popular age group for the X-ray exams is in 60 – 70 years with 421 occurrences. The calculated median age was 65 years. With a standard deviation of 17.23 years. Most patients in the hospital are older, witch partially can explain a higher occurrence of overweight patients and the importance of non-standard patients in this study.

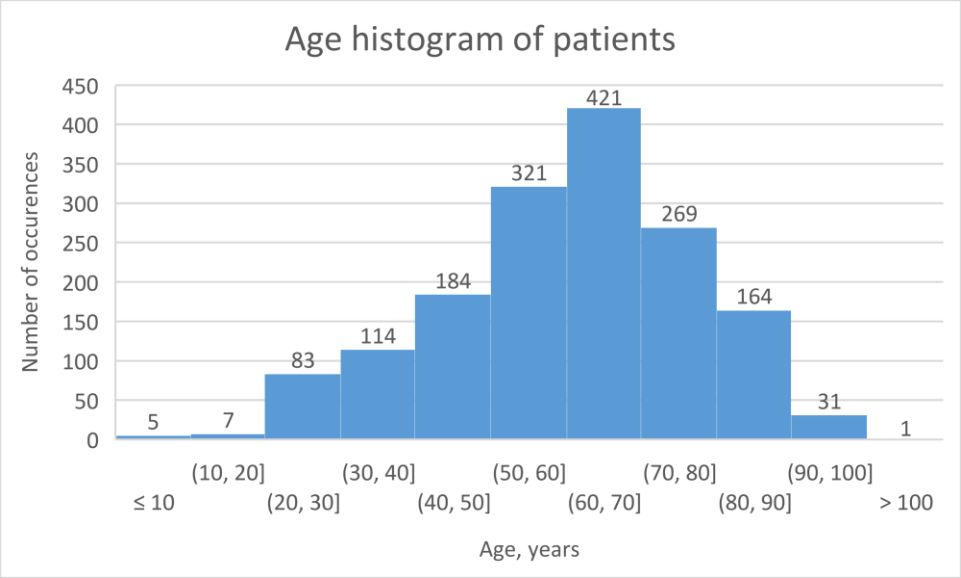

Fig. 7. Age distribution of patients.

4.3.2. Investigation of DAP values for standard and non-standard patients

Results obtained after making 2 boxplots in the Chest PA exam for all patients and filtered out standard patients can be seen in figure 8 and figure 9.

For standard Chest PA exam patients, the median dose was equal to mean dose at 0.69 dGy·cm^2, minimum dose was at 0.44 dGy·cm^2 and maximum dose was at 1.02 dGy·cm^2 and compared to not filtered patient sample maximum dose for all patients was 2.24 dGy·cm^2 with high number of outliers at higher doses. For non-standard patients mean dose was 0.92 dGy·cm^2 and higher than the median dose of 0.78 dGy·cm^2 which can be connected with the higher average weight of non-standard patients of 82.9 kg.

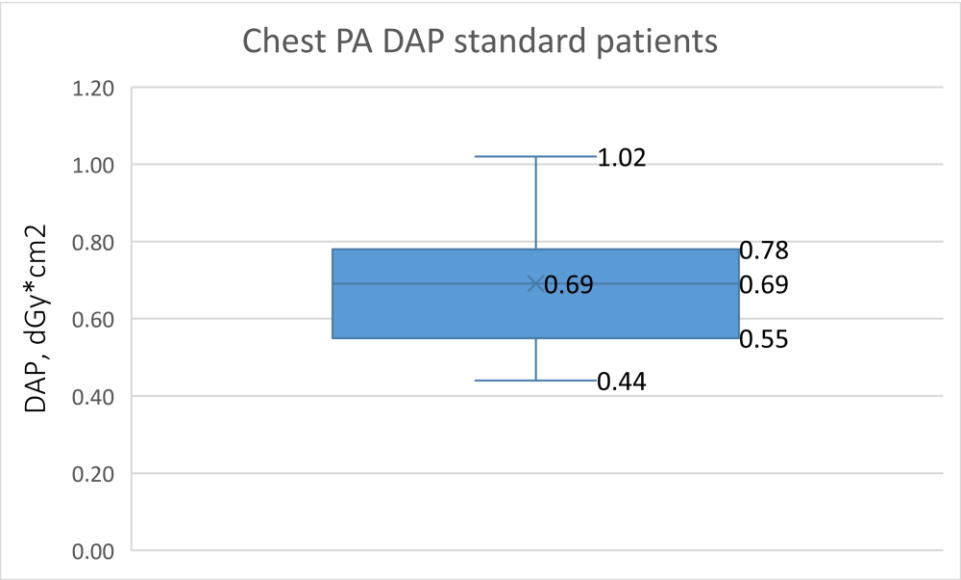

Fig. 8 Chest PA DAP for standard patients

No outliers were registered for standard Chest PA patients. Though top whisker is more stretched for the box plot for standard patients compared to non-standard patients.

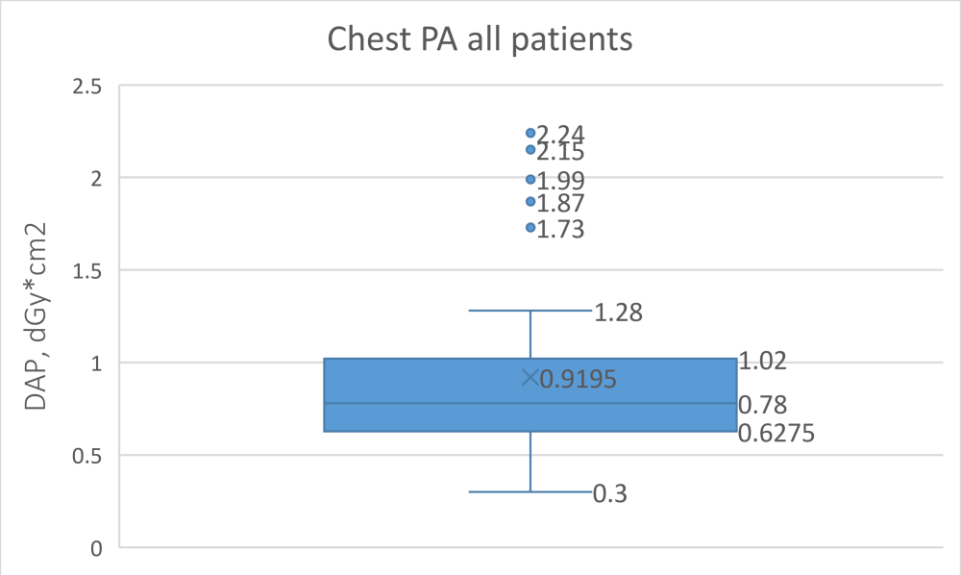

Fig. 9 Chest PA DAP for all patients

The comparison for the 75th percentiles for Chest PA patients in both samples can be seen in Table 9.

Table 9 Comparison of 75th percentiles for Chest PA exams for standard and non-standard patients

Chest PA	**Dose area product (dGy·cm^2)**	**Standard deviation**
75th percentile for standard patients	0.795	±0.16
75th percentile for all patients	1.02	±0.47

It is seen that for all patients dose area product values for Chest PA examinations are somewhat higher than for standard patients and the standard deviation values are also higher. This can be explained since all patient weights were registered and the dose depends greatly on weight.

For the Pelvis AP exam for all patients and filtered out standard patients box plots can be seen in figure 10 and figure 11.

For standard Pelvis AP exam patients the median dose was 2.49 dGy·cm^2 and it was close to mean dose at 2.61 dGy·cm^2, minimum doses were equal for both samples and they were at 1.36 dGy·cm^2. The maximum dose for all patients was at 34.8 dGy·cm^2 and it was much higher compared to standard patient samples maximum dose at 4.32 dGy·cm^2 with a few outliers at higher doses. For non-standard patients mean dose was 9.76 dGy·cm^2 and higher than the median dose of 6.92 dGy·cm^2

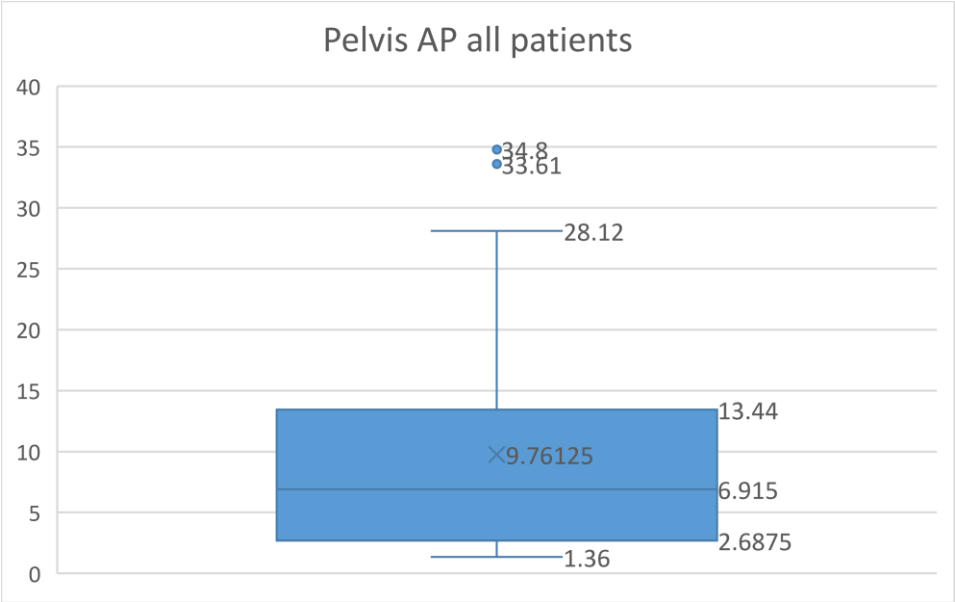

Fig. 10 Pelvis AP DAP for all patients

No outliers were registered for standard Pelvis AP patients. Though top whisker is more stretched for the box plot for non-standard patients compared to standard patients.

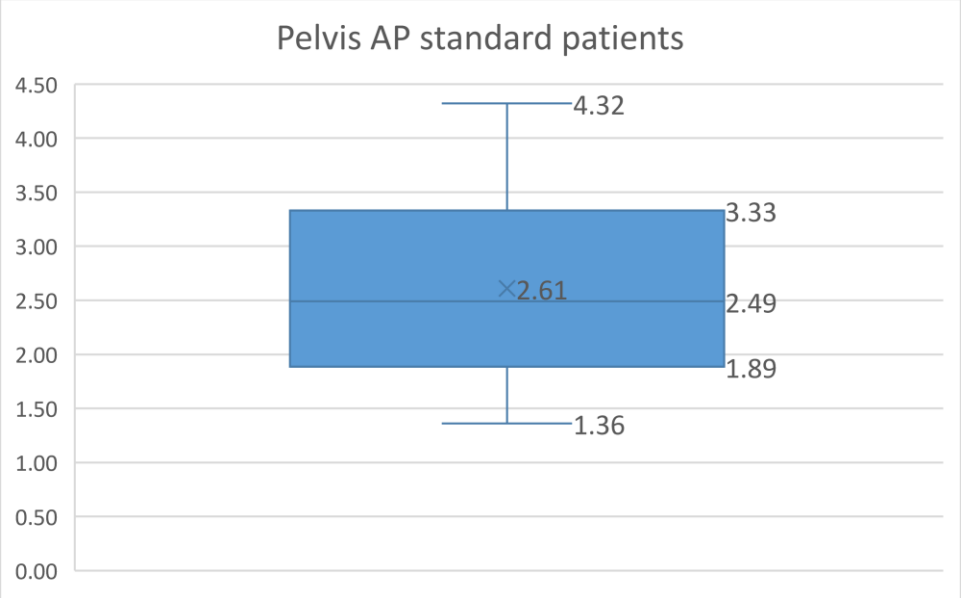

Fig. 11 Pelvis AP DAP for standard patients

It is can be seen in Table 10 that for non-standard patients dose area product for Pelvis AP examination is much higher than for standard patients and the standard deviation is over 10 times higher, which might be explained by anatomical nuances of the human body, that when the weight is higher, fat primarily collects in the belly region of the body.

Table 10 Comparison of 75th percentiles for Pelvis AP exams for standard and non-standard patients

Pelvis AP	**Dose area product (dGy·cm^2)**	**Standard deviation**
75th percentile for standard patients	3.33	±0.86
75th percentile for all patients	13.44	±8.99

4.4. Application of DICOM image for analysis of doses

It is seen from the data that most patients could not be considered standard. That's why this study is more of a metastudy of 200 exam per anatomical area for the most popular X-ray procedures in the hospital:

- Chest PA
- Pelvis AP
- Cervical AP
- Cervical LAT
- Thoracic AP
- Thoracic LAT
- Lumbar AP
- Lumbar LAT

Other exams were less popular and to reach 200 procedures per anatomical area milestone, data from a much longer period should be collected.

A total number of 1600 exam data was analyzed. The data was collected from December 2019 till April 2020. Random DICOM files were chosen for this study and were downloaded from a local PACS system. Information from DICOM files was extracted using custom software written in JavaScript and main points from the files were extracted: patient age, anodic tube voltage, exposure time, tube current, exposure, and DAP readings. No private patient data was used. The main part of the program code can be seen in Appendix 1.

```
>
PS C:\dicom> node .\dicom.js
Parsing DICOM files
3267 file(s) found
File: 3267 of 3267 pictures/easter/SondraSalte20200412/series-000000/image-000001.dcmDONE!
DICOM files parsed!
Creating excel sheets!
PS C:\dicom>
```

Fig. 12 An example of data extraction in the program

Chest PA

For Chest PA exams the minimum dose was 0.07 dGy·cm^2, while the maximum dose was 4.12 dGy·cm^2, mean was at 0.92 dGy·cm^2 while the median was 0.80 dGy·cm^2 which can explain a higher number of outliers in the higher dose area and a higher number of people receiving higher doses. The box plot for Chest PA can be seen in figure 13.

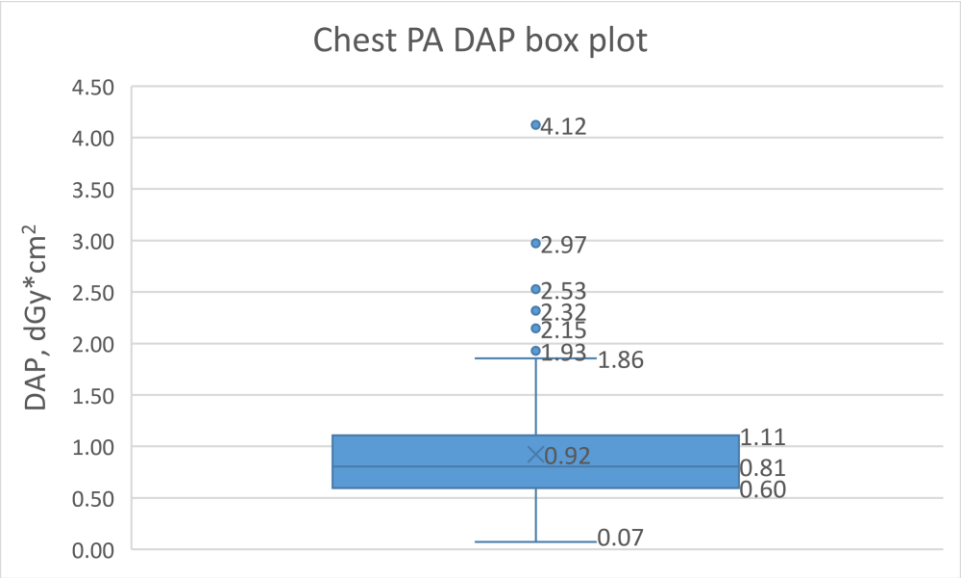

Fig. 13 Chest PA DAP box plot

The standard deviation for dose is equal to 0.52 dGy·cm^2 which may not be very high. The 75th percentile dose of the Chest PA exams is equal to 1.11 dGy·cm^2. This is considerably lower than the national diagnostic reference level in Lithuania for chest PA at 2 dGy·cm^2. [20]

Pelvis AP

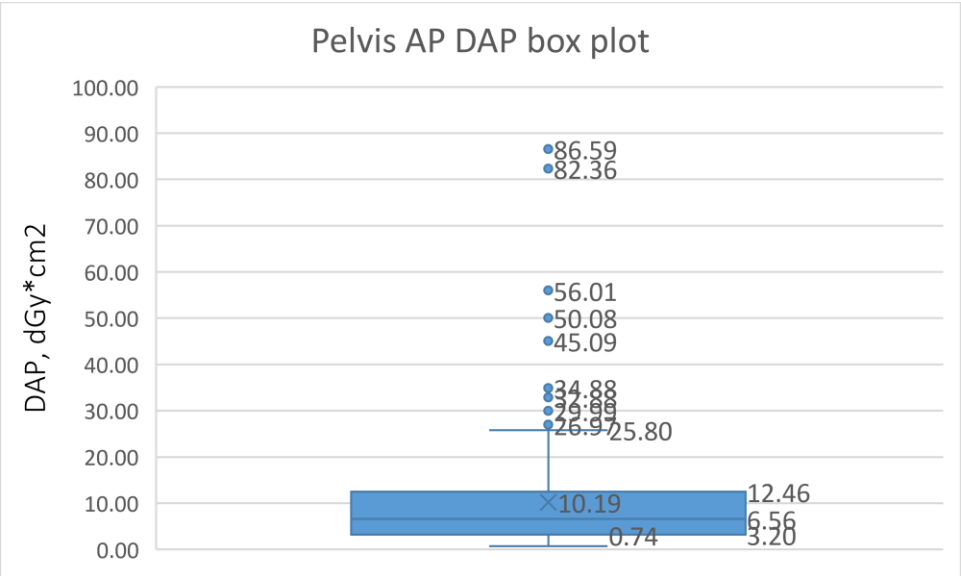

Fig. 14 Pelvis AP DAP box plot

For Pelvis AP exams the minimum dose was 0.74 dGy·cm^2, while the maximum dose was 86.59 dGy·cm^2, mean was at 10.19 dGy·cm^2 while the median was 6.55 dGy·cm^2 which can explain a higher number of outliers in the higher dose area and a higher number of people receiving higher doses. The box plot for Pelvis AP can be seen in figure 14

High number of outliers on top of boxplot, the standard deviation measured at 12.58 dGy·cm^2 it is considerably higher than the median or mean dose values. The 75th percentile dose of Pelvis AP exams is equal to 12.46 dGy·cm^2. This is considerably lower than the national diagnostic reference level in Lithuania for Pelvis AP at 30 dGy·cm^2 [20].

THORACIC AP

For Thoracic AP exams the minimum dose was 0.55 dGy·cm^2, while the maximum dose was 23.47 dGy·cm^2, mean was at 6.23 dGy·cm^2 while the median was 4.35 dGy·cm^2 this can be explained with a higher number of outliers in the higher dose area and a higher number of people receiving higher doses. The box plot for TH AP can be seen in figure 15.

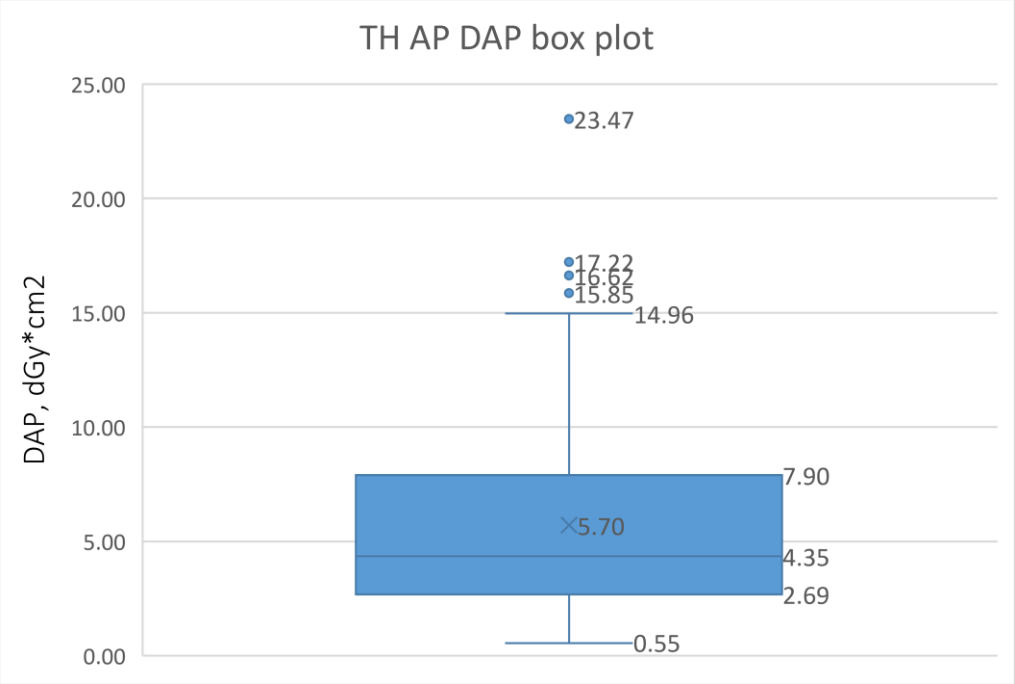

Fig. 15 TH AP DAP box plot

As with the other exams, all of the outliers are on the higher end of the boxplot, the standard deviation measured at 8.5 dGy·cm2, It is somewhat higher than the median or mean dose values. It is seen in figure 15 that the difference between the median and 75th percentile is much higher at 3.55 compared to the difference between the median and the 25th percentile at 1.66. The 75th percentile dose of TH AP exams is equal to 7.90 dGy·cm^2. This is considerably lower than the national diagnostic reference level in Lithuania for TH AP at 16 dGy·cm^2 [20].

THORACIC LAT

For Thoracic LAT exams the minimum dose was 1.0 dGy·cm^2, while the maximum dose was high at 43.97 dGy·cm^2, mean was at 6.50 dGy·cm^2 while the median was 4.58 dGy·cm^2. A number of outliers were registered in the higher range of doses. Whisker is somewhat longer for the higher dose range (difference between 75th percentile and maximum dose) than for the lower doses (difference between 25th percentile and minimum dose). The box plot for TH LAT can be seen in figure 16.

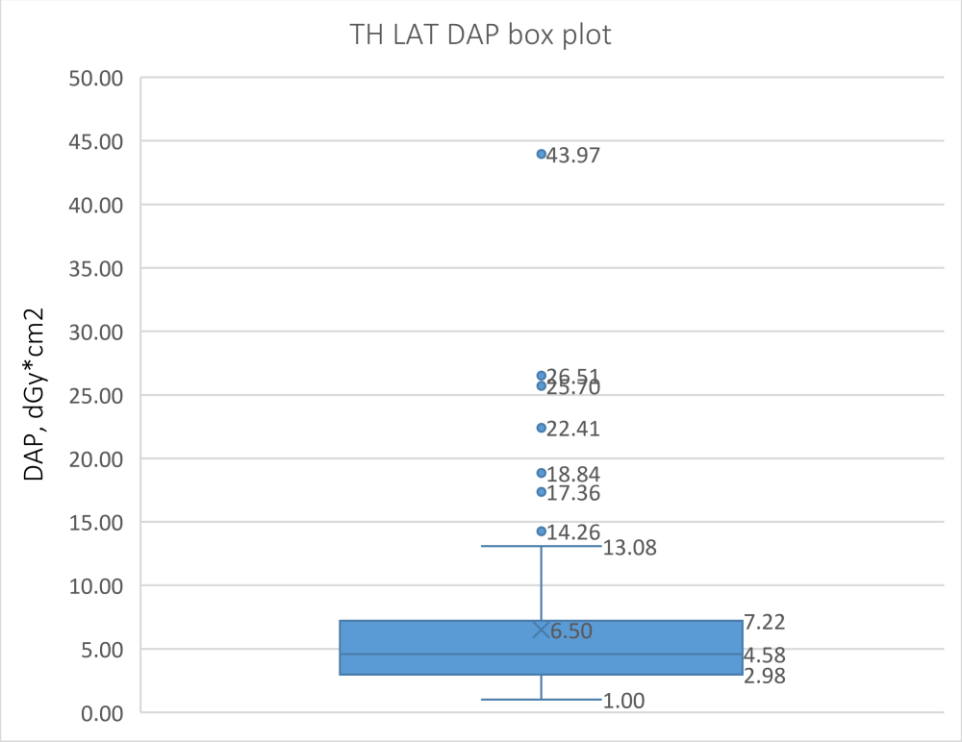

Fig. 16 TH LAT DAP box plot

The standard deviation was measured at 6.57 dGy·cm2, It is a bit higher than the median or mean dose values. It is seen in figure 16 that the difference between the median and 75th percentile is much higher at 2.68 dGy·cm^2 compared to the difference between the median and the 25th percentile at 1.60. dGy·cm^2. The 75th percentile dose of TH LAT exams is equal to 7.22 dGy·cm^2. This is much lower than the national diagnostic reference level in Lithuania for TH LAT at 22 dGy·cm^2 [20].

Lumbar AP

For the Lumbar AP exams, the minimum dose was 1.88 dGy·cm^2, while the maximum dose was very high at 203.97 dGy·cm^2, the median dose was at 13.35 dGy·cm^2 while mean was much higher at 21.78 dGy·cm^2. A high number of outliers at very high doses were registered. Whisker is much longer for the higher dose range (difference between 75th percentile and maximum dose) than for the lower doses (difference between 25th percentile and minimum dose). The box plot for Lumbar AP can be seen in figure 17.

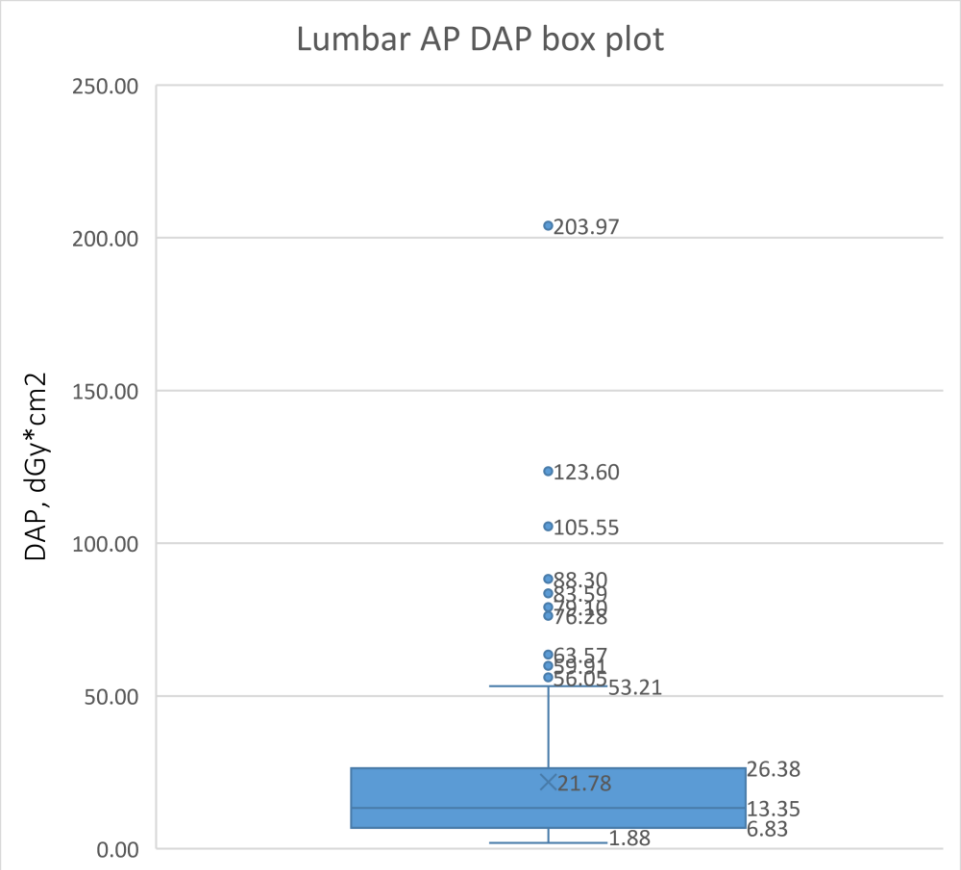

Fig. 17 Lumbar AP DAP box plot

The standard deviation is very high at 24.71 dGy·cm^2, It is a bit higher than the mean dose though much higher than the median dose value. It is seen in figure 17 that the difference between the median and 75th percentile is much higher at 13.03 dGy·cm^2 compared to the difference between the median ant the 25th percentile at 6.52 dGy·cm^2. The 75th percentile dose of Lumbar AP exams is equal to 26.38 dGy·cm^2. This is considerably higher than the national diagnostic reference level in Lithuania for Lumbar AP at 15 dGy·cm^2 [20]. These results are somewhat similar to Pelvis AP results since exposure regions anatomically in both projections are similar.

Lumbar LAT

For the Lumbar LAT exams, the minimum dose value was 2.73 dGy·cm^2, while the maximum dose was high at 88.96 dGy·cm^2, the median dose was at 15.74 dGy·cm^2 while mean was higher at 18.41 dGy·cm^2. A high number of outliers at high dose range were registered. Whisker is much longer for

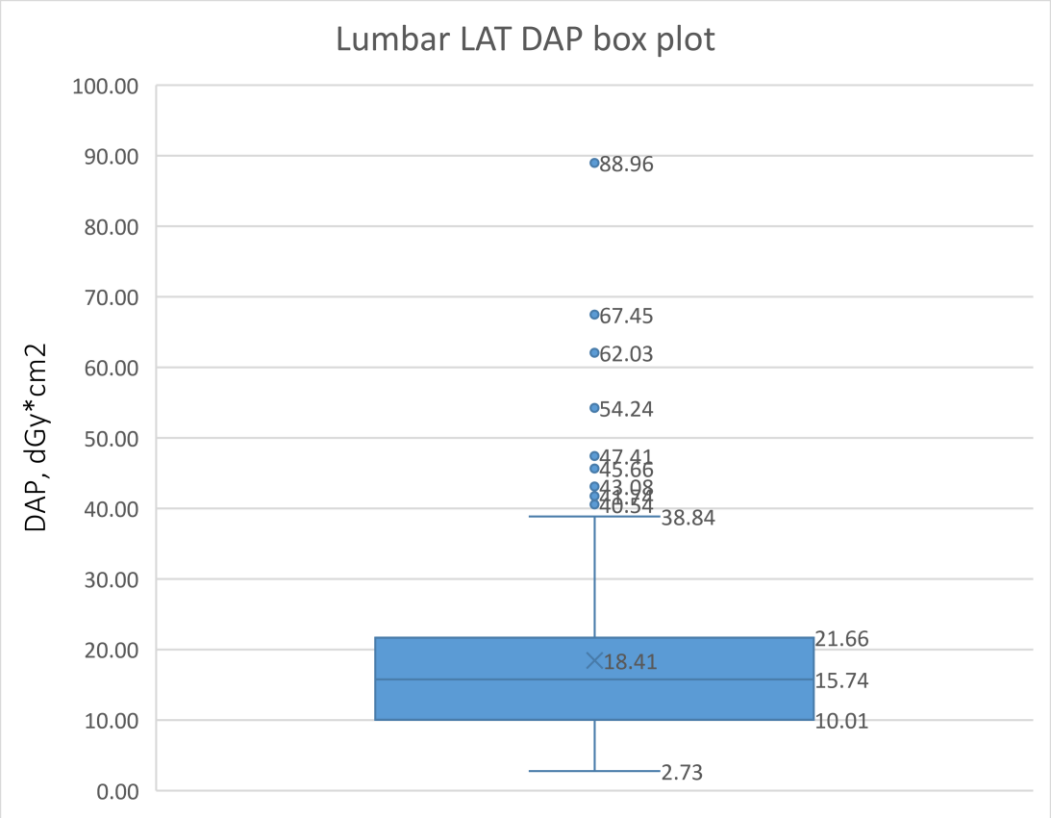

Fig. 18 Lumbar LAT DAP box plot

the higher dose range (and many outliers also) than for the lower doses. The box plot for Lumbar LAT can be seen in figure 18.

The standard deviation is very high at 12.44 dGy·cm^2, It is a bit lower than both the mean dose and median dose values. It is seen in figure 18 that the difference between the median and 75th percentile is somewhat similar at 6.22 dGy·cm^2 compared to the difference between the median and the 25th percentile at 5.73 dGy·cm^2. The 75th percentile dose of Lumbar LAT exams is equal to 21.66 dGy·cm^2. This is over 2 times lower than the national diagnostic reference level in Lithuania for Lumbar LAT at 50 dGy·cm^2 [20]. Though these results are somewhat lower than Lumbar AP doses.

Cervical AP

For the Cervical AP exams, the minimum dose value was 0.32 dGy·cm^2, while the maximum dose was high at 5.5 dGy·cm^2, the median dose was at 0.9 dGy·cm^2 while the mean was higher at 1.13 dGy·cm^2. A high number of outliers at high dose range were registered. Whisker is much longer for the higher dose range than for the lower doses. The box plot for Cervical AP can be seen in figure 19.

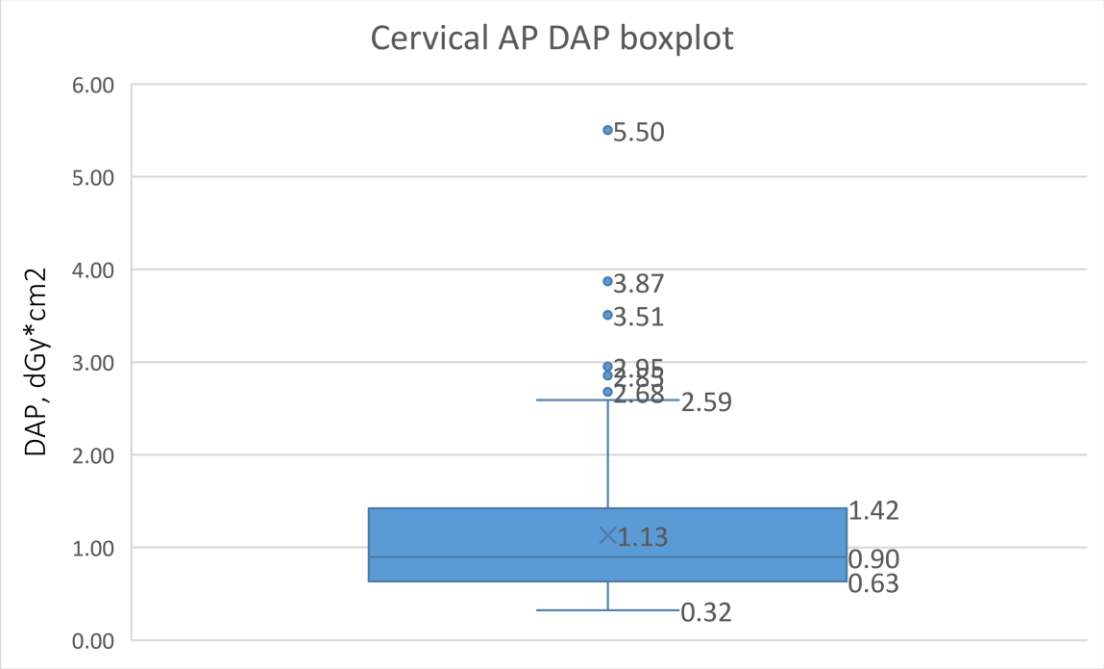

Fig. 19 Cervical AP DAP box plot

The standard deviation is not that high at 0.71 dGy·cm^2, It is a bit lower than both the mean dose and median dose values. As it can be seen in figure 19, the difference between the median and 75th percentile is high at 0.52 dGy·cm^2 compared to the difference between the median ant the 25th percentile at 0.27 dGy·cm^2. The 75th percentile dose of Cervical AP exams is equal to 1.42 dGy·cm^2. There is no diagnostic reference level for the Cervical AP exam in Lithuania, but it lower than in the UK (1.5 dGy·cm^2) []that has DRL for the cervical AP exam.

Cervical LAT

For the Cervical LAT exams, the minimum dose value was 0.17 dGy·cm^2, while the maximum dose was high at 8.82 dGy·cm^2, the median dose was at 3.17 dGy·cm^2 while mean was a bit higher at 3.27 dGy·cm^2. No outliers were registered in this plot. Whisker is much longer for the higher dose range than for the lower doses. The box plot for Cervical LAT can be seen in figure 20.

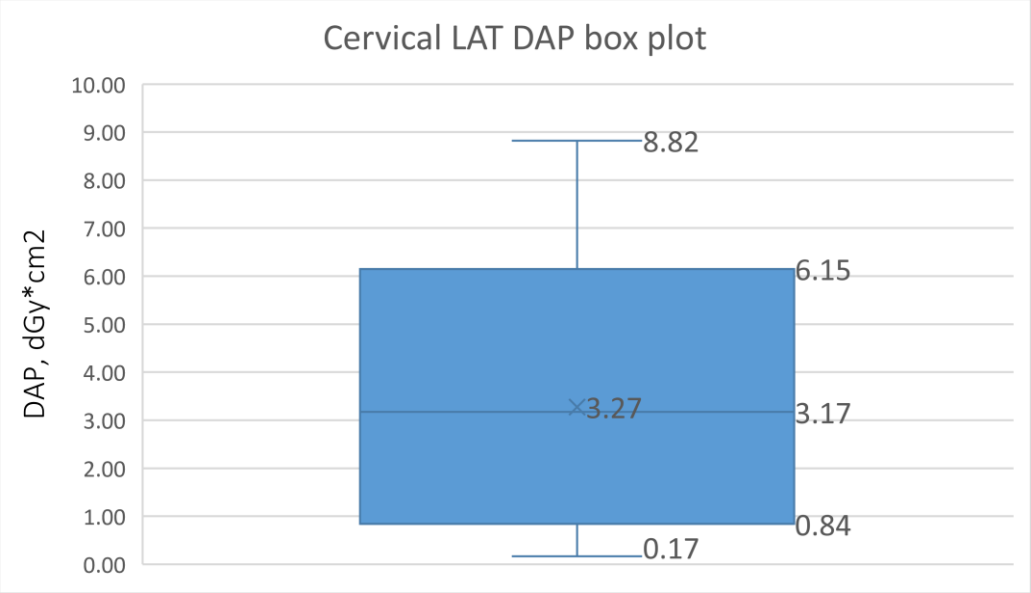

Fig. 20 Cervical LAT DAP box plot

The standard deviation is considerably higher than for the Cervical AP exams at 2.34 dGy·cm^2. Though it is a bit lower than both the mean dose and median dose values. As it can be seen in figure 20, the difference between the median and 75th percentile is at 2.98 dGy·cm^2 compared to the difference between the median ant the 25th percentile at 2.33 dGy·cm^2. The 75th percentile dose of Cervical LAT exams is equal to 6.15 dGy·cm^2. There is no diagnostic reference level for the Cervical LAT exam in Lithuania, but it much higher than in the UK (1.5 dGy·cm^2) that has DRL for the cervical LAT exam [].

A comparison of measured 75th percentile DAP and diagnostic reference levels in Lithuania can be seen in table 11.

Table 11 Comparison of measured 75th percentile dose with national DRL's of Lithuania

Exam type	**Measured 75th percentile DAP (dGy·cm^2)**	**Diagnostic reference level in Lithuania (dGy·cm^2)**
Chest PA	1.11	2
Pelvis AP	12.47	30
TH AP	7.90	16
TH LAT	6.42	22
Lumbar AP	26.39	15
Lumbar LAT	21.68	50
Cervical AP	1.42	-
Cervical LAT	6.17	-

Conclusions

1. To assess the reliability of DAP readings for the patient's dose assessment a coefficient between DAP readings on the X-ray machine console and TLD measured doses has been calculated. The obtained value k = 1.012, was close to k = 1.0 thus indicating that DAP readings may be used for further dose evaluations.

2. The average weight value of the real patients was found to be 82.9 kg, which is much higher than the upper limit to a standard patient of 75 kg. Standard patients undergoing chest PA X-ray exam received a dose of 0.78 dGy·cm^2 while non-standard patients received a dose of 1.02 dGy·cm^2 which was considerably lower as compared to national DRL of Lithuania of 2 dGy·cm^2. For pelvis AP examinations the dose to the standard patients was 3.33 dGy·cm^2 while for non-standard patients – 13.34 dGy·cm^2 and was also lower as compared to the national DRL of 30 dGy·cm^2.According to recommendations, all data was calculated within the 75th percentile of the investigated dose values.

3. The retrospective analysis of DICOM images including standard and non-standard patients revealed that the Chest PA dose was 1.11 dGy·cm^2, Pelvis AP – 12.47 dGy·cm^2 which was similar to the doses obtained performing *in situ* survey for non-standard patient: 1.02 dGy·cm^2 for Chest PA and 13.34 dGy·cm^2 for Pelvis AP and considerably lower as compared to National DRLs. (All data was calculated within 75th percentile of the investigated dose values).

4. Based on performed investigation following local dose reference levels (for DAP measurements) for Kaunas Republican hospital were proposed: for Chest PA – 0.15 Gy·cm^2, for Pelvis AP – 1.3 Gy·cm^2; for Thoracic AP – 0.8 Gy·cm^2; for Thoracic LAT – 0.7 Gy·cm^2; for Lumbar AP – 2.7 Gy·cm^2 ; for Lumbar LAT – 2.2 Gy·cm^2 ; for Cervical AP – 0.2 Gy·cm^2 and for Cervical LAT – 0.7 Gy·cm^2.

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Appendices

Appendix 1. Main part of the source code for DICOM data extraction

Used library (npm package) for parsing DICOM files: “dicom-parser” (https://www.npmjs.com/package/dicom-parser)
TagMap contains DICOM tags and intermediate variable properties, used for structuring and filtering of parsed data. (Filtering is required, so not everything gets saved in .xlsx files, only things we need).
Saving data to .xlsx sheets is straightforward: just save each parsed record to each row of the sheet. (Sheets are grouped by protocol name (or processing description))

```
let tagMap = {
    '(0008,0020)': 'studyDate',
    '(0010,0030)': 'birthDate',
    '(0010,0040)': 'sex',
    '(0008,103E)': 'description',
    '(0010,1010)': 'age',
    '(0011,1042)': 'projection',
    '(0018,0015)': 'bodyPart',
    '(0018,0060)': 'KVP',
    '(0018,1030)': 'protocolName',
    '(0018,1400)': 'processingDescription',
    '(0018,1150)': 'exposureTime',
    '(0018,1151)': 'xrayTubeCurrent',
    '(0018,1153)': 'exposureInuAs',
    '(0018,115E)': 'DAP',
    '(0008,0070)': 'manufacturer',
    '(0018,5101)': 'viewposition',
};
```

```
function parseFile(byteArray, fileName) {
    var dataSet = dicomParser.parseDicom(byteArray);

    // Initial object with null values
    let info = {...};

    try {
        var keys = [];
        for (let propertyName in dataSet.elements) {
            if (dataSet.elements.hasOwnProperty(propertyName)) {
                keys.push(propertyName);
            }
        }
        keys.sort();

        for (var k = 0; k < keys.length; k++) {
            let propertyName = keys[k];
            var element = dataSet.elements[propertyName];

            let tag = `(${element.tag.substring(1, 5)},${element.tag.substring(5, 9)})`.toUpperCase();
            if (tagMap[tag]) {
                info[tagMap[tag]] = dataSet.string(propertyName);
            }
        }
    } catch (err) {
        console.log('Exception while parsing file. ' + fileName);
        console.log(err);
        return null;
    }
    return info;
}
```