

## Review article

# OPTIMISATION OF RADIOGRAPHIC PROCEDURES – LUMBAR SPINE IMAGING IN GENERAL RADIOGRAPHY

## OPTIMIZACIJA POSEGOV V RADIOLOŠKI TEHNOLOGIJI – SLIKANJE LEDVENE HRBTENICE V SPLOŠNI RADIOLOGIJI

**Erna ALUKIĆ<sup>1,\*</sup>, Nika ZALOKAR<sup>2</sup>, Nejc MEKIŠ<sup>1</sup>**

<sup>1</sup> University of Ljubljana, Faculty of health sciences, Medical imaging and radiotherapy department, Zdravstvena pot 5, 1000 Ljubljana, Slovenia

<sup>2</sup> University Medical Centre Ljubljana, Clinical Institute of Radiology, Zaloška 7, 1000 Ljubljana, Slovenia

\* Corresponding author: [erna.alukic@zf.uni-lj.si](mailto:erna.alukic@zf.uni-lj.si)

Received: 29. 7. 2021

Accepted: 31. 8. 2021

<https://doi.org/10.47724/MIRTJ.2021.i01.a001>

### ABSTRACT

**Purpose:** Any use of ionizing radiation must be justified and the benefit must be greater than the harm it causes. Imaging must be performed with the lowest possible dose received by the patient, while maintaining optimal radiographic image quality. Imaging of the lumbar spine is a relatively high dose imaging procedure. This systematic review aims to explore optimisation options to reduce patient exposure, while maintaining radiographic quality during plain lumbar spine imaging.

**Methods:** A systematic review of the literature from the databases Pub Med Central, EBSCOhost including CINAHL, Cochrane Library, Web of Science, Science Direct, DiKUL and Springer Link was conducted. The documents were fully accessible and in the English language.

**Results:** 26 experimental studies were included in the analysis. There are many optimisation methods: changing the tube potential, comparison of different projections, use of shielding, primary beam collimation, increasing the source-to-image receptor distance, compression of the imaged area, using the air gap technique, evaluation of the need for additional projections, and rotating the patient depending on the tube side. On average, the dose is reduced by 44%. Studies that also evaluated the quality of radiographs found all radiographs to be diagnostically acceptable.

**Conclusion:** The results confirm a reasonable use of methods to optimize radiation exposure and to maintain an optimal image quality of radiographs. A systematic review for each specific area in general radiography should be conducted in the future.

**Keywords:** lumbar spine imaging, optimisation, dose reduction, low dose, image quality

### IZVLEČEK

**Namen:** Vsaka raba virov sevanja mora biti upravičena, korist, ki jo dosežemo z uporabo ionizirajočih virov pa mora biti večja od škode, ki jo povzroči. Postopke slikanja moramo izvajati tako, da pacient pri slikanju prejme najnižjo dozo, ki je še razumno dosegljiva ob optimalni kakovosti rentgenograma. Slikanje ledvene hrbtenice spada med preiskave z relativno visoko dozo ionizirajočega sevanja. Namen sistematičnega pregleda je raziskati možnosti optimizacije v smislu zniževanja doze na paciente in hkratni ohranitvi kakovosti rentgenogramov na področju slikanja ledvene hrbtenice v splošni radiologiji.

**Metode:** Narejen je bil sistematični pregled literature s pregledom podatkovnih baz Pub Med Central, EBSCOhost preko CINAHL, Cochrane Library, Web of Science, Science Direct, DiKUL in Springer Link. Dokumenti so bili iskani v polnem besedilu in v angleškem jeziku.

**Rezultati:** V analizo je bilo vključenih 26 eksperimentalnih raziskav. Kot možnosti za optimizacijo so bile uporabljene različne metode spreminjanja napetosti, primerjava različnih projekcij, uporaba svinčenih zaščit, zaslanjanje primarnega polja, povečanje razdalje od izvora do slikovnega sprejemnika, kompresija slikanega področja, ocenjevanje potrebe po dodatni projekciji slikanja ter obračanje pacienta glede na postavitev rentgenske cevi. Povprečna doza ionizirajočega sevanja se zmanjša za 44 %. Raziskave, v katerih so poleg doze ocenjevali še kakovost rengenogramov, med ocenami niso opazili statistično značilnih razlik oz. rentgenogrami so bili diagnostično sprejemljivi.

**Zaključek:** Rezultati potrjujejo smiselno uporabo metod za optimizacijo tako na področju zniževanja doze kot tudi ohranjanja optimalne kakovosti rentgenogramov. V prihodnje bi bilo smiselno narediti sistematični pregled za vsako posamezno področje v splošni radiologiji.

**Ključne besede:** slikanje ledvene hrbtenice, optimizacija, zniževanje doze, kakovost rengenograma

## INTRODUCTION

In the last century, population exposure has increased with the use of man-made radioactive sources. Despite the harmful effects of ionising radiation, its use in medicine has significant diagnostic and therapeutic benefits, increasing the frequency of X-ray examinations. Any use of radiation sources must be justified, and the benefit of the use must be greater than the harm it causes (1,2).

Radiation protection results in avoiding unnecessary or unproductive irradiation, which is achieved by general principles of radiation protection. The first principle is the justification principle. The procedure may be performed if it is clinically indicated and if a greater benefit can be expected than the harm caused by the radiation. The referring physician and the radiologist are responsible for the procedure, and they must be familiar with the radiation exposures involved in certain radiologic procedures. The goal is to assess whether the radiological procedure will improve diagnosis or treatment and provide the necessary information. The second principle is the principle of optimisation. Radiation doses and the frequency of patients irradiated must be as low as possible, considering the purpose of the radiation application. Quality and safety are essential characteristics for effective and successful medical treatment of patients. Radiation dose and radiographic image quality must be optimised for proper radiological procedures. Optimising means finding the lowest possible dose at which the purpose of the radiologic procedure is still achieved. By justifying the indication for the radiological procedure and optimising the equipment, techniques, and proper use of radiation sources, the procedure can be optimised. The third principle is the principle of applying dose limits. Departments and facilities may vary in their radiation doses. The causes of these differences must be identified and prevented (3). Radiographic procedures are used only when the diagnosis cannot be made by other methods that are not as risky for the patient (4). We must follow the ALARA principle (As Low As Reasonably Achievable), which means that the procedure must be performed at the lowest possible dose that still gives the optimal quality of the images or procedure (4,5). By reducing the radiation dose, patients are protected from genetic damage (2). According to the 2007 data from International Commission on Radiological Protection (ICRP) 103, the most radiosensitive organs with the highest weighting factor (0.12) are the breasts, lungs, stomach, colon, and bone marrow. The weighting factor of the specific organ represents the average of both sexes and all age groups (3).

Several optimisation studies have been conducted. They are all based on reducing patient exposure whilst still obtaining images of high diagnostic quality. There are no strict guidelines in the European guidelines for performing imaging, but they are supposed to present the basic criteria that have proved appropriate in the past (4). Dose limits do not exist for radiological procedures (6). However, reference values are established for each examination to aid and provide basic guidance in the optimisation of protocols (4). The establishment of reference values is one of the mechanisms by means of which patient overexposure is detected. Diagnostic reference levels (DRLs) represent dose values in diagnostic radiological procedures. They represent a dividing line between optimized and non-optimized

radiological practice. DRLs are not expected to be exceeded during optimized procedures. The health authorities set the values in collaboration with the national health and radiation protection authorities (3).

Among the most common reasons for visiting a primary care physician is low back pain leading to imaging of the lumbar spine (7,8). Lumbar spine imaging is one of the examinations with the highest radiation exposure in plain radiography with a relatively high radiation dose (4,9–12). According to the European Commission (13), Slovenia is among the countries where patients receive the lowest dose area product (DAP) values for lumbar spine imaging. Many radiosensitive organs located near the lumbar spine (breasts, lungs, stomach, colon, gonads) must be protected (14).

General principles in accordance with the optimisation of the protocol (4):

- quality control of the radiographic equipment,
- correct positioning of the patient (the proper technique of patient positioning – as the lowest dose with the highest radiogram quality),
- imaging field collimation that leads to a better quality of the radiogram with lower doses,
- use of shielding (protective aprons for radiosensitive organ protection),
- proper exposition parameters (tube current, tube voltage and other parameters that influence the dose and quality of the radiograms) and
- proper image annotation;

Regular checks of the doses received and comparison with diagnostic reference values represent excellent radiological practice as the use of these methods has led to progressively lower exposure doses in many countries (15).

The aim of this systematic review was to investigate optimisation options to reduce the dose to patients while maintaining the quality of radiographic images in plain lumbar spine radiography. The focus was on the lumbar spine imaging, where the patient receives the highest dose in plain radiography. The aim was to investigate all optimisation possibilities in this area for easy transfer to clinical practice.

## METHODS

We performed a systematic review and quantitative analysis. All studies that were included addressed lumbar spine radiography and optimisation, and were fully accessible. The literature search was conducted in English. Since radiography is a relatively new field in which new opportunities for protocol optimisation in terms of the ALARA principle are constantly emerging and new ways of performing examinations are being discovered as technology evolves, no additional restrictions were placed on the selection of studies.

## Document references

Based on the research title, we selected key words that apply to the topic under study. First, we conducted the search in the Pub Med Central, EBSCOhost including CINAHL and Cochrane Library. Since few documents were found, the scope of the study was expanded to include sources found in Web of Science, Science Direct, DiKUL and Springer Link.

## Methods of document identification

All documents were searched using the following keywords: radiography, lumbar spine and dose reduction. The keywords were selected based on the aim and objectives of this systematic review. The keyword for image quality assessment was not used. Nevertheless, this area was considered. The following exclusion criteria were also used: Magnetic Resonance, Computed Tomography, CT and MRI, as a large number of documents related to MR and CT appeared in the first search.

The retrieved documents were reviewed based on the title and the abstract. All documents that were not suitable for the research were excluded. All documents that did not relate to plain radiography of the lumbar spine and those that did not relate to the process of optimisation or dose reduction were also excluded. Then, all duplicate documents were eliminated. Finally, all articles were read and two documents were excluded because they were not fully accessible and one document did not refer to the study area.

The criteria for including the documents in the analysis were studies covering the topic of plain radiography, lumbar

spine imaging, documents that examined dose reduction, documents with full accessibility and in English, as well as quantitative, qualitative, and experimental studies.

Exclusion criteria were all the documents that did not relate to plain radiography imaging, documents that covered other areas of general radiography and did not involve optimisation or dose reduction, and all documents in duplicate or without full accessibility.

## Methods for quality evaluation of research

When evaluating the quality of research works included in this systematic review, a few main features were checked. The following features were taken into consideration:

- a country in which the study was performed,
- research design,
- subjects under investigation (participants),
- inspected area,
- inspected results,
- measurement tools,
- results.

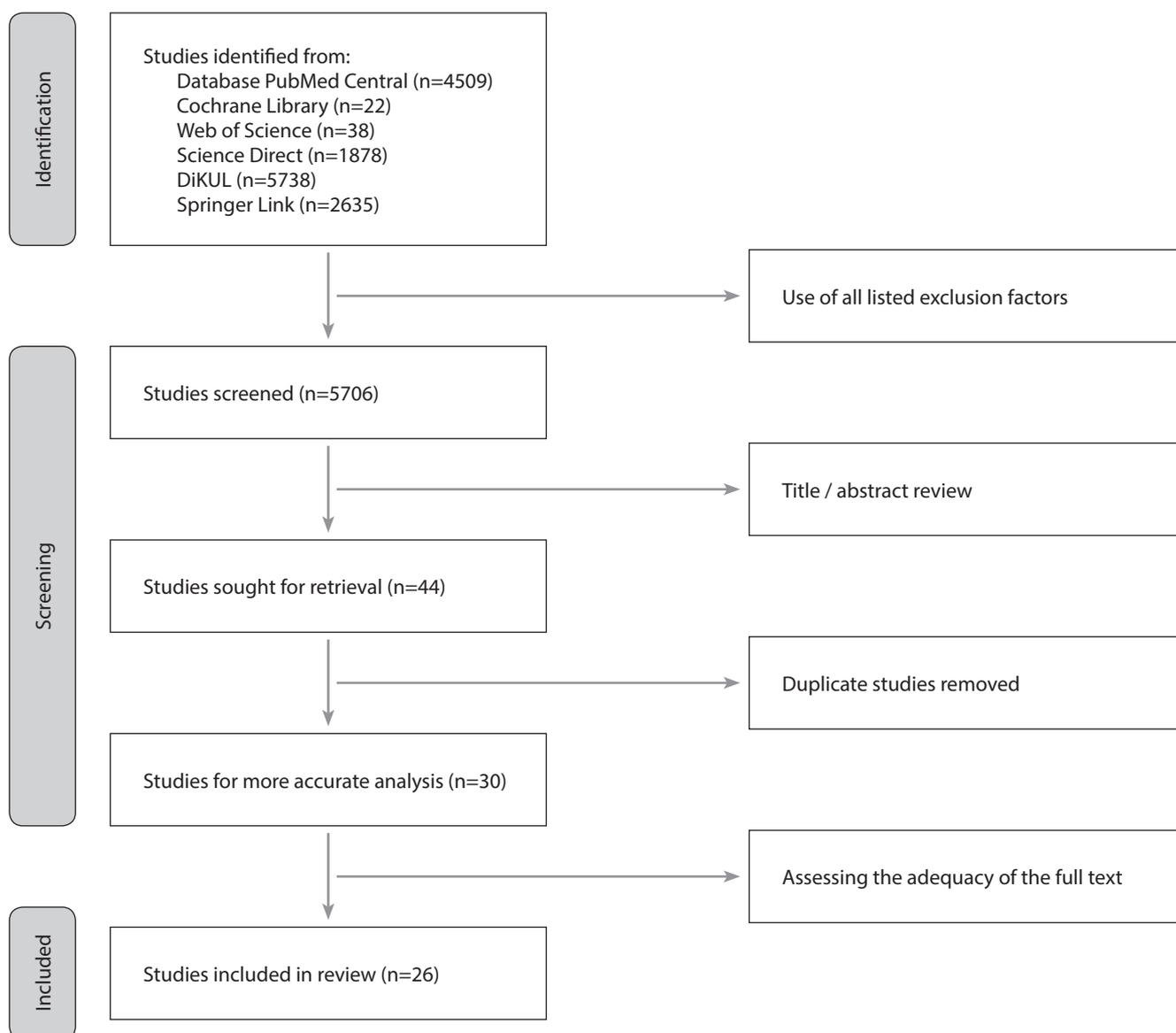


Figure 1: Flow chart of the included studies

## RESULTS

The literature search in all seven previously mentioned databases yielded 14,832 results (articles). Based on this, exclusion factors were used for several search results. After using exclusion factors, all the articles were screened by title and abstract and all the articles that did not describe lumbar spine radiography or did not describe dose optimisation were excluded. Afterwards, duplicate documents were encountered. After all of the above exclusions had been made, all of the remaining articles were read and four of them were excluded; three were excluded because they were not consistent with the aim of the study and the fourth was excluded because it was not within the scope of general radiography. Figure 1 presents a flow chart of the studies selected.

### Main characteristics of investigated papers

Twenty-six papers were included in our systematic literature review. All key data from our review are presented in Table 1. The data are ordered by year of publication, from the oldest to the most recent. The presented data include the country of research, the research methodology and the reviewed subjects on whom the research was conducted, the reviewed research area, which measurement devices were used, keywords, and finally, the results and conclusions of the research reviewed.

### Result analysis

Papers describing optimisation techniques in lumbar spine radiography have been studied in several countries around the world. Those countries are Finland (16), Australia (17,34,39,41), Ireland (18,19,21,22,25), China (20), Sweden (24,26,33), Kuwait (23), United Kingdom (27,30,36), Slovenia (28,35,37), Iran (29,32), Israel (31), Croatia (38) and Malta (40).

The research methodology was experimental in almost all studies, except for three studies (16,32,39) in which the research methodology was a retrospective study of lumbar spine images. In most cases, the research was performed on an anthropomorphic phantom (17,20,34,41,22–25,29–31,33), in a few studies the research was performed on patients only (27,36–38), and some of them performed a combined study first on a phantom and then on patients (18,19,21,26,28,35,40). The sample size of the examined patient studies varied from study to study. The smallest sample size of patients studied was three (26), and the largest sample size was 110 (38). The investigators studied the radiation dose to the patient and/or phantom in all papers, but the measurement tool for the dose measurements varied from study to study. The dose was measured using TLDs (16,18–22,25,28,33), ionization chambers (17,26,30), with some mathematical formulas and using conversion factors (21,23,32), DAP meters (27,35,36,38,40), based on calculations with the PCXMC program and Monte Carlo simulation (24,29–31,35–38,41) and other ways (24,29,34). Image quality was not checked in a large number of the papers examined (17,20,34,37,25–29,31–33).

There were several ways to achieve dose optimisation in lumbar spine radiography. In 7 papers, the researchers used different tube potentials (kV) (21–24,34,39,41), different mAs (41), in 5 papers they used alternative positioning of the patient, in which the patient or phantom was rotated to different positions (19,27,29–31,35–37), and 2 studies

used lead shielding as a method of radiation dose reduction (25,28). Four papers investigated increasing the distance (focus-film distance and source-to-image distance) on the radiation dose to the patient during lumbar spine radiography (17,18,22,41), and some of the papers evaluate the effect of proper collimation (32,33,38). Other methods described to reduce radiation dose include the need for additional image projection (16), changing the patient position on the cathode and anode sides of the X-ray tube (20), using a carbon fibre cassette and a faster film/screen combination (22), compression of the body part being examined (26), the effect of an additional copper filter (41), and replacing an antiscatter grid with an air-gap technique (40).

On average, the ESD decreased the most by 65% (18), dose to gonads by 42% (25), effective dose by 58% (29), DAP by 59% (27) and the dose to other inspected organs decreased the most by 80%, where they evaluate the use of lead shielding to reduce the radiation dose to breasts (28).

Of the 26 reviewed papers, 14 (16,18,38–41,19,21–24,30,35,36) examined the effect of the optimisation procedure on image quality. In eleven papers, the researchers found no statistically significant difference between image quality before and after optimisation (16,18,41,19,22,30,35,36,38–40). In three others (21,23,24), the researchers concluded that the optimisation procedure decreased image quality but the images were still diagnostically acceptable.

## DISCUSSION

The aim of this systematic literature review was to investigate the options for radiation dose optimisation in lumbar spine radiography. This was selected because lumbar spine radiography is a procedure that delivers the highest radiation dose to the patient in general radiography. There are many ways to achieve dose optimisation in lumbar spine radiography, but all the inspected methods have their limitations. We did not limit our literature review according to the year of publication of the articles as we were interested in the trends of changing measuring equipment, the transition from the film/screen system, and CR and DR detectors.

All the 20 inspected papers offer a large variety of achieved dose reduction in lumbar spine radiography. The method used was mainly experimental. An experimental research method offers the researcher an inspection and testing of new methods for dose reduction and its comparison with previously established methods. In this way, the efficiency and safety of the new protocol can be evaluated. The disadvantage of the experimental method is mainly its ethical concerns; therefore, several researchers investigated their newly established methods on an anthropomorphic phantom (17,20,34,41,22–25,29–31,33) before carrying on with the study on the patients. The use of ionising radiation may negatively affect patients (1,2). However, the ethical concern can be avoided if the newly established research methodology is first performed on a phantom and results of the optimisation procedures are in that manner primarily investigated (18,19,21,26,28,35,40). Some of the investigated papers describe that the research was performed on patients, but many of them performed the primary analysis on a phantom before carrying on with the study on patients.

All the reviewed studies have proven that radiation dose in

Table 1: Main features of the studies included in the analysis.

RESEARCH	COUNTRY	RESEARCH METHOD & SUBJECT	INSPECTED AREA	AIM OF THE STUDY	MEASURING EQUIPMENT	KEYNOTES	RESULTS AND COCNLUSION
Moilanen et al., 1983 (16)	Finland	Retrospective study - image evaluation n=250	Lumbar spine in AP, LAT projection and lumbo-sacral joint (LS) view in LAT projection	Evaluation of the necessity of LS joint imaging and the influence on gonadal dose.	Termoluminiscent dosimeters (TLD) were used to measure the dose. The images were retrospectively evaluated by radiologists.	Film/screen combination was used.	In 91% of the cases the third image (LS joint) does not contribute any diagnostic information.  The dose was doubled, when three projections are used compared of two projections.
Dilger et al., 1997 (17)	Australia	Experimental research - Phantom study	Lumbar spine (AP and LAT projection)	Comparison of radiation dose to patient at different focus film distance (FFD was 100cm and 200cm).	A chamber dosimeter to measure entrance testicular dose.	Film/screen combination was used.	The increase of FFD decreases radiation dose for AP projection by approximately 30% and for LAT projection by 70%.
Brennan and Nash, 1998 (18)	Ireland	Experimental research - Phantom and patient study (n=21; females between 55 and 65 kg)	Lumbar spine in LAT projection	Comparison of radiation dose to patient at different focus film distance (FFD was 100cm, 130cm and 200cm) and influence on image quality.	Entrance surface dose (ESD) was measured using TLDs.  Image quality assessment was performed by two radiographers and one radiologist based on quality criteria by the European Commission.	Film/screen combination was used.  entrance surface dose and dose to ovaries were measured.	The larger FFD resulted in 65.5% of ESD reduction in the phantom and 44.1% reduction in the patient study.  63-69% dose reduction to ovaries when a larger FFD was used.  There were no statistically significant difference in image quality.
Brennan in Madigan, 2000 (19)	Ireland	Experimental research – Phantom and patient study (n=30; 70 ± 5kg, 1,55-1,75m)	Lumbar spine in AP and PA projection	The influence of PA projection on ESD and image quality.	ESD was measured with TLDs.  The diameter of the investigated part was measured to determine the compression in PA projection.  Image quality assessment was performed by three clinicians based on quality criteria by the European Commission.	In PA projection the diameter of the investigated part was decreased by 9.6%. That has influenced the AEC to terminate the exposure sooner than in AP projection.	Decrease of ESD in PA projection by 38.9% in phantom study and by 38.6% in patient study.  There was no statistically significant difference in image quality.
Fung in Gilboy, 2000 (20)	China	Experimental research - Phantom study	Lumbar spine in AP and LAT projection	Radiation dose to selected radiosensitive organs (ovaries, testicles, breasts, thyroid and eyes) based on position of the patient regarding the tube side (cathode-anode).	ESD was measured using TLDs.	Known fact based on the literature review is that there is higher intensity of radiation on the cathode side of the tube.	When the patient's head is orientated towards the anode side of the x-ray tube, the ovaries and testicles received 17% and 12% higher dose on average, respectively, in LAT projection and 17% and 12% higher, respectively, in AP projection.

<b>RESEARCH</b>	<b>COUNTRY</b>	<b>RESEARCH METHOD &amp; SUBJECT</b>	<b>INSPECTED AREA</b>	<b>AIM OF THE STUDY</b>	<b>MEASURING EQUIPMENT</b>	<b>KEYNOTES</b>	<b>RESULTS AND COCNLUSION</b>
Doherty et al., 2003 (21)	Ireland	Experimental research - Phantom and patient study (n=59; 70±10kg, 1.65±0.1m)	Lumbar spine in AP and LAT projection	Increase of the anode voltage (kV) and its influence on ESD, effective dose (ED) and image quality.	The ESD was measured using TLDs, ED was calculated, and image quality assessment was performed by three radiologists based on quality criteria by the European Commission.	The increase of tube voltage results in faster termination of AEC due to higher energy of the photons.  The comparison of tube voltage in the patient study was 81 kV and 96 kV in the AP and 90 kV and 102 kV in the LAT projection.	Decrease of ESD by 40.4% in AP and 34.8% in LAT projection.  Decrease of ED for 29.9% in AP and 24.6% in LAT projection.  The reduction of image quality in the AP projection was 18.3% and 10.1% in LAT but all images were still diagnostically acceptable.
Grondin et al., 2004 (22)	Ireland	Experimental research - Phantom study	Lumbar spine in AP and LAT projection	Increase of anode voltage (kV), FFD, c carbon fibre cassette, a faster film/ screen combination and their influence on radiation dose and image quality	ESD was measured using TLDs  Image quality assessment was performed by two radiographers and one physicist based on quality criteria by the European Commission.	Increase of tube voltage in the AP projection from 66 kV to 96 kV and in LAT projection from 81 kV to 102 kV and the increase of SID from 100 cm to 130 cm	Dose reduction with the use of optimised procedure (higher kV, FFD, faster film/screen combination and use of carbon fibre cassette) has decreased by 66% with no significant changes of image quality
Brindhavan et al., 2005 (23)	Kuwait	Experimental research - Phantom study	Lumbar spine in AP projection	The effect of increased tube voltage on radiation dose and image quality in two CR systems.	A chamber dosimeter was used for ESD, ovary dose and effective dose were calculated using conversion factors.  Image quality was assessed using visual grading scale (VGS) based on quality criteria by the European Commission and the SNR was calculated.	Three different tube voltages were used.  9 evaluators = 5 radiologists, 1 physicist and 3 radiographers	The decrease of ESD, ovary dose and effective dose between 25% and 50% depending on the used CR system.  Significant decrease of image quality, however the images were still diagnostically acceptable.
Geijer and Persliden, 2005 (24)	Sweden	Experimental research - Phantom study	Lumbar spine in AP projection	To evaluate the relation between kV and image quality at the constant effective dose.	Entrance dose was recorded with a solid-state detector, while organ doses and effective dose were calculated with PCXMC program (Monte Carlo simulation).  Image quality was assessed using VGS bases on quality criteria by the European Commission by eight radiologists.	The tube voltage (kV) was changed between 48 and 125 and the tube load (mAs) was adjusted to keep a constant effective dose.	At the constant effective dose, a lower tube voltage delivers better image quality than higher tube voltage. But due to the use of AEC which is set for a constant detector dose this cannot be done.

<b>RESEARCH</b>	<b>COUNTRY</b>	<b>RESEARCH METHOD &amp; SUBJECT</b>	<b>INSPECTED AREA</b>	<b>AIM OF THE STUDY</b>	<b>MEASURING EQUIPMENT</b>	<b>KEYNOTES</b>	<b>RESULTS AND COCNLUSION</b>
Clancy et al., 2010 (25)	Ireland	Experimental research - Phantom study	Lumbar spine in AP and LAT projection	To determine the effect of the use and different positioning of lead shielding on dose to ovaries, uterus and testicles in lumbar spine radiography.	Dose to the mentioned organs was measured using TLDs.	They used different positioning of lead shielding (no shield, tube side, wrap-around and Bucky side).	In the AP projection dose to the testicles was decreased by 42% when a tube side apron was used and for 36% when the wrap-around apron was used. In the LAT projection, the observed dose reduction to the testicles was 12% with the use of wrap-around apron. No reduction to other inspected organs was observed.
Olsson et al., 2010 (26)	Sweden	Experimental research - Phantom and patient study (n=3)	Lumbar spine in AP projection	To determine the effect of compression technique to obtain the optimal image quality and radiation dose.	Kerma-area product (KAP) was measured with a ionisation chamber.	Compression for three volunteers to determine the effect of compression was simulated with Comp-X (carbon fibre plate)	With the use of compression dose reduction of up to 50% or more can be obtained.
Davis in Hopkins, 2013 (27)	UK	Experimental research - Patient study (n=30)	Lumbar spine in LAT projection	Comparison of radiation dose received by the patient in LAT projection of lumbar spine when the patient is lying on the side and on the back with the horizontal x-ray beam and its influence on image quality.	They measured DAP using a DAP meter.	Rotating the patients from their side to their back caused an increase in tissue thickness. The simulations of different lateral thickness were carried out using PMMA.	59% of DAP decrease was found when the patient was lying on the side rather than on the back. With the use of horizontal central ray position, the tube voltage should be increased to decrease the radiation dose.
Mekiš et al., 2013 (28)	Slovenia	Experimental research - Phantom and patient study (n=100 female patients)	Lumbar spine in AP and LAT projection	To evaluate the influence of lead shielding on dose to breasts in lumbar spine radiography.	Dose was measured using TLDs for both projections.	The use of tube voltage used in clinical environment was not in accordance with European guidelines.	The use of lead shielding has decreased the radiation dose to breasts by approximately 80%.
Chaparian et al., 2014 (29)	Iran	Experimental research - Phantom study	Lumbar spine in different projections	The aim of the study was to determine the ED, dose to radiosensitive organs and effective risk.	The measurements of entrance skin exposure were performed using solid-state dosimeter, while effective dose and risk of exposure induced cancer death were calculated using PCXMC program (Monte Carlo simulation).	The use of different projections has a different effect on radiosensitive organs as they lie closer or further from the primary field.	Lower effective dose in PA projection by 51% and effective dose and risk by 58% in comparison to AP projection.  Lower effective dose in LLAT projection by 53% and effective dose and risk by 58% in comparison to RLAT projection.

RESEARCH	COUNTRY	RESEARCH METHOD & SUBJECT	INSPECTED AREA	AIM OF THE STUDY	MEASURING EQUIPMENT	KEYNOTES	RESULTS AND COCNLUSION
Davey in England, 2015 (30)	United Kingdom	Experimental research - Phantom study	Lumbar spine imaging in AP and PA projection	Comparing AP and PA projection at various tube voltage (kV) using CR and compare effective dose, dose to organs and image quality	ESD was measured using an ion chambers in Multi-O-Meter. Effective dose and dose to selected organs was calculated using PCXMC program (Monte Carlo simulation). The image quality was assessed using VGA by 5 radiography students.	The use of PA projection has an effect of object magnification in comparison to the AP projection.	Magnification in the PA projection was 8%. The effective dose reduction was 19.7% and the organ that had the most dose reduction (74%) was the stomach. There were no significant differences between the images made in AP and PA projection.
Ben-Shlomo et al., 2016 (31)	Israel	Experimental research - Phantom study	Lumbar spine in four different projections AP, PA, LLAT, RLAT	To calculate and compare the effective dose for lumbar spine radiography for adults and 10-year-old children.	The calculations were made using PCXMC program (Monte Carlo simulation).	The authors want to determine the less radiosensitive side of the body for lumbar spine imaging.	RLAT projection has been proven to deliver 28% lower ED in comparison to LLAT projection. PA projection has been proven to deliver 48% lower ED in comparison to the AP projection.
Karami, in Zabihzadeh 2017 (32)	Iran	Retrospective study - 830 images of lumbar spine in the AP projection	Lumbar spine in AP projection	To evaluate the collimation protocol in two Iranian general hospitals.	A mathematical formula to determine the oversized primary field was used.	The authors state that this has happened due to implementation of digital detectors.	The area of diagnostic interest was 1.26 times higher than it is supposed to be – this cause higher dose too. In 62% of radiographs evaluated, ovaries were included in the primary beam.
Robinson et al., 2017 (33)	Sweden	Experimental research - Phantom study	Thoraco-lumbar spine (scoliosis protocol)	The aim was to determine the differences to organ dose, effective dose and effective risk comparing tight and loose collimation in thoraco-lumbar spine imaging.	The TLDs were used to measure ESD, organ doses and the effective risk were calculated using a mathematical formula.	The patients that suffer from scoliosis usually get imaged quite frequently and because they are at a young age a tight collimation protocol should be used to protect as many organs.	The organ dose with the use of loose collimation protocol increased from 31 to 571% The effective risk was 3.3 times higher when using a loose collimation.
Shanahan, 2017 (34)	Australia	Phantom study	Lumbar spine in AP projection	To compare the ESD based on the 15% kVp rule and simplified 10 kVp rule for CR and DR systems (system 1 and 2), and for Projection VR - virtual radiography simulation (system 3).	The ESD was measured using NanoDOT, single point dosimeters .	The 15% rule states that if you increase the tube voltage for 15%, then the tube time current product has to be decreased by 50% to get the same exposure. The exposure maintenance formula uses the increase in SID.	Increasing kVp resulted in reduction of ESD by 59,5% (system1), 60,8% (system2) and 60,3% (system 3). Increasing SID resulted in reduction of ESD by 22,3% (system1), 18,8% (system2) and 23,5% (system 3).
Alukić et al., 2018 (35)	Slovenia	Experimental research - Phantom and patient study (n=100)	Lumbar spine, AP and PA projection	Compare patient radiation dose and image quality using AP and PA projection.	DAP meter was used to measure DAP and effective dose was calculated using PCXMC program (Monte Carlo simulation). image quality was evaluate by three radiologists using criteria in European guidelines.	Body mass index (BMI), DAP, exposure index (EXI), mAs, image field size and source to patient distance were acquired.	No significant difference in image field size, DAP and image quality but in a PA projection a significant reduction of thickness of abdomen by 10%, DAP by 27% and effective dose by 53% compared to AP projection. No significant difference in image quality between AP and PA projection.

<b>RESEARCH</b>	<b>COUNTRY</b>	<b>RESEARCH METHOD &amp; SUBJECT</b>	<b>INSPECTED AREA</b>	<b>AIM OF THE STUDY</b>	<b>MEASURING EQUIPMENT</b>	<b>KEYNOTES</b>	<b>RESULTS AND COCNLUSION</b>
Green et al., 2019 (36)	United Kingdom	Experimental research - Patient study (n=80; 60-100 kg)	Lumbar spine, AP and PA projection	Evaluate dose and image quality in both projections and survey current UK practice	DAP meter was used to measure the DAP and effective dose was calculated using PCXMC program (Monte Carlo simulation). Image quality was evaluate by two radiologist using criteria in European guidelines.	BMI, DAP and mAs were acquired	Effective dose was reduced by 41% when PA projection was used with no difference in image quality.
Alukić et al., 2019 (37)	Slovenia	Experimental research - Patient study (n=100)	Lumbar spine, AP and PA projection	Determine the effect of the PA projection on effective dose and the absorbed organ dose	Calculation with PCXMC program (Monte Carlo simulation).	Image quality was not measured.	Significant reduction of ESD by 33% and, effective dose by 53% and 64% average reduction of the absorbed organ doses when the PA projection was used.
Pazanin et al., 2020 (38)	Croatia	Experimental research – Patient study (n=110)	Lumbar spine, AP and LAT projection	Determine the influence of optimal and standard (non-optimal) collimation on radiation dose and image quality	DAP meter was used to measure the DAP, absorbed and effective dose were calculated using PCXMC program (Monte Carlo simulation). Image quality was evaluate by two radiologist and a radiographer using criteria in European guidelines.	BMI, exposure conditions, image field size and DAP were acquired.	Optimal collimation reduced image field size by 40%, effective dose by 48% and absorbed dose by 41% for the AP and effective dose by 48% and absorbed dose by 10% for the LAT projection. Image quality improves by 24% in the LAT projection, and showed no statistically significant difference for AP projection with the use of optimal collimation.
Peacock et al., 2020 (39)	Australia	Retrospective study - 91 images of lumbar spine in the LAT projection	Lumbar spine in LAT projection	To assess the effects of the high tube potential on image quality using DR system and validate effect on dose saving technique	Collection of data from PACS system. Image quality was assessed by five senior radiographers using a 15-point visual grading analysis.	kV, mAs, deviation index and DAP were acquired.	The reduction of DAP with the use of higher kVp was shown for 40 lateral lumbar spine radiographs with no statistically significant difference in image quality.
Bellizzi et al., 2020 (40)	Malta	Experimental research – Phantom and patient study (n=50)	Lumbar spine in LAT projection	To investigate the possibility of replacing an antiscatter grid with an air gap technique to reduce dose.	DAP meter was used to measure the DAP. Image quality was assessed by five radiologists using a 15-point visual grading analysis.	/	Application of air gap technique resulted in a statistically significant reduction in DAP by 72%, image quality between the two techniques was not significant.
Lai et al., 2020 (41)	Australia	Experimental research - Phantom study	Lumbar spine in LAT projection	Determine the influence of different exposure parameters – source to detector distance, tube potential, tube time current and additional copper filter for reduction of effective dose.	Effective dose was calculated using PCXMC program (Monte Carlo simulation). Contrast-to-noise ratio and magnification were calculated using ImageJ.	Exposure factors, SSD, focal-skin distance, collimation field and additional filtration parameters were acquired for each image acquisition.	The highest effective dose was found with the use of lowest SSD, lowest tube potential, highest tube time current and without additional copper filter.

the lumbar spine can be optimised based on their proposed methodology. The results cannot be generalised due to the uniqueness of each study methodology and measurement technique.

With the lowering of tube voltage (kV), the patient's dose can be reduced (21–24,34,39,41). It has already been proven that the increase of tube voltage increases the penetration of x-rays, and as a consequence, the automatic exposure control terminates exposure earlier due to more x-rays hitting the ionising chamber of AEC. The negative effect of tube voltage increase is its influence on image quality. The use of modern materials and digital technology that offers image postprocessing, such as changing the window centre and level, can reduce the negative effect of tube voltage increase on image quality (24). In the past, the increase of tube voltage in screen-film technology has led to a decrease of image contrast (4). The inspected papers investigated the influence of tube voltage increase performed on different imaging systems (screen-film and digital). Therefore, the results between studies differ. A film-screen system was in use in research until 2004. The research on two CR detectors was firstly mentioned in 2005 (23).

Therefore, in the literature review, it could be observed how measurement equipment for dose has changed over the years and where they first used TLDs and chamber dosimeters (16–23,25,26). In 2013, Davis and Hopkins first mentioned the use of the DAP meter (27).

In the early years, dose on organs could not be measured. The record of organ dose was first mentioned in 2005 (24), and then again nine years later in 2014 (29). Since 2014, the Monte Carlo simulation has been used in eight different articles (29–31,35–38,41). For calculations of an effective dose, organ dose weight and height of the patient, imaging field size, DAP, and total filtration are needed (42).

In studies that investigate an alternative projection in lumbar spine radiography (19,27,29–31,35–37), researchers should be careful that the radiograph's quality remains optimal and that the changing of the position does not result in excessive magnification of the inspected object. As described in the reviewed papers, the magnification of the inspected object can be enlarged up to the point that it still does not interfere with the diagnostically important information and radiologist's perception. The further away the inspected object is from the image receptor, the greater the magnification is (19). The use of alternative projections is limited in its use since it cannot be used in all diagnostic departments due to the patient's status or mobility. Changing the projection from AP to PA projection in lumbar spine radiography greatly influences dose reduction to different organs in the patient's body. Due to anatomy, some bones in the human body (pelvis) can work as a shield for some organs that lie behind the bone structure. Another advantage of the PA projection is that some radiosensitive organs lie further from the irradiation source and, due to the inverse square law, those organs receive a lower radiation dose than in the AP projection.

Lead shielding has proven to be an effective dose reduction technique when used inside or outside the primary field. The use of lead protection over the radiosensitive organs can decrease the dose received by those organs (25,28). Proper collimation of the primary beam also has a considerable effect on the patient's radiation dose (32,33,38). When deciding

which organs to shield or put outside the primary field, the ICRP document must be considered to determine which organs have the highest tissue weighting factors (3). However, tissue weighting factors change over time based on the results of studies investigating the ionising radiation effect on the human body, the organs, and cells. For example, before the year 2007, the gonads were the organ with the highest tissue weighting factor (6), so the research was mainly focused on dose reduction to the gonads. After the new publication from the ICRP in 2007, the gonads are now the sixth organ based on tissue weighting factor (3). The organs with the highest tissue weighting factor of 0.12 are now the breast, lungs, bone marrow, stomach, and colon, so the research of dose reduction has nowadays changed to described (most radiosensitive) organs.

Along with the most frequently described research methods, other reviewed methods have also been proven to be effective as a dose reduction technique, such as the change of the patient position based on the tube side (cathode-anode) (20). It has been proven that the radiation intensity is lower on the anode side; therefore, the part of the body with a smaller diameter (legs) has to be on that side of the x-ray tube and the larger diameter (head) on the cathode side (14). Also, a well-known example of the compression of the body part is in daily use in mammography since the dose reduction to the patient and improved image quality were proven. That kind of dose reduction technique can also be implemented to other positioning in radiography (26). The ALARA principle states that even with a minimum dose, if receiving that dose has no benefit, it should be avoided. This was indicated in a study that examined the necessity for a third projection (lumbosacral joint in lateral view). It was found that the use of the third projection doubled the dose compared to two projections (AP and lateral) (16). Finally, a significant manner of optimising the dose is by using the air gap technique instead of the anti-scatter grid (40). The reduction in scattered radiation reaching the detector is achieved by increasing the distance between the effective scatter point source and the image receptor. This increased distance increases the chance that the scatter radiations path will not reach the receptor and; therefore, not reduce image contrast.

We recommend that the studies that were performed only on an anthropomorphic phantom be conducted also on patients in order to determine their influence on dose reduction on actual patients before using them in the clinical environment. In dose optimisation, image quality cannot be decreased to the extent that the diagnostically important information is lost. If diagnostically important information was missed, this would result in even greater harm to the patient in comparison to the damage that would result due to ionising radiation. In a large variety of the reviewed papers, the influence of dose optimisation on image quality has not been inspected (17,20,34,37,25–29,31–33). When the image quality was inspected, all three groups of experts were used, but not all together. We propose that all three groups of experts (radiographer, radiologist, and medical physicist) evaluate the image quality to obtain the optimal results due to their different backgrounds. Radiologists would inspect the diagnostic part of the image, radiographers the technical part of the image and the medical physicists would give an objective quality of the image.

Due to rapid changes in technology, new ideas and methods of dose reduction techniques will surely appear. The researchers should remember to inspect the effects of the optimisation technique on image quality and not only on radiation dose.

### Limitations of the systematic review

This review has screened a variety of research papers in the field of dose reduction in lumbar spine radiography that may lead to easier implication in a clinical setting. Based on the reviewed literature, this type of qualitative study was not found in this field.

Limitations of our review are that only articles in English were included in the review and that not all papers examined the effects of dose optimisation on image quality.

### CONCLUSION

Regardless of the many uses and advantages of ionising radiation in X-ray diagnostics, it has a negative effect on the human body, so the ALARA principle must be observed. This means that the patient is imaged with the lowest possible radiation dose with optimal image quality based on the expected pathology. Based on the inspected studies, it can be concluded that there are many different ways to achieve dose reduction in lumbar spine radiography, while keeping the quality of the images in the diagnostically acceptable range. The methods studied for dose optimisation are different lead shield positioning, proper collimation, alternative patient positioning, patient positioning based on the orientation of the X-ray tube, increasing the source-to-image receptor distance, and changing the exposure factors, among others. All the methods studied were found to be effective in dose optimisation as the average dose reduction in all the studies was 44%. The studies that investigated the effect of dose optimisation on image quality concluded that there was no significant reduction in image quality and that all images were still diagnostically acceptable. We did not find a large systematic review examining dose optimisation techniques and image quality in lumbar spine radiography. Due to a wide variety of procedures, techniques, and modalities in radiology, this cannot be generalised to all diagnostic procedures. Therefore, a targeted review should be performed separately for each procedure and modality.

### REFERENCES

1. Aldrich JE, Duran E, Dunlop P, Mayo JR. Optimization of dose and image quality for computed radiography and digital radiography. *J Digit Imaging*. 2006;19(2):126–31.
2. Tabor L, Jevtić V, Pavčnik D. Radiologija: diagnostične slikovne metode in intervencijska radiologija. *Med Razgl*. 2001;(3):135–49.
3. International Commission on Radiological Protection. The 2007 recommendations of the International Commission on Radiological Protection. Valentin J, editor. Orlando: Elsevier, published for the International Commission on Radiological Protection, cop. 2007; 2007. 332 p.
4. European Commission. European Guidelines on Quality Criteria for Diagnostic Radiographic Images, EUR 16260 EN [Internet]. 1996. Available from: <https://www.sprmn.pt/pdf/EuropeanGuidelineseur16260.pdf>
5. Medic M, Zibert J, Mekis N. Radiološka tehnologija 1, učbenik za študente radiološke tehnologije. Ljubljana: Zdravstvena fakulteta; 2017.
6. International Commission on Radiological Protection. 1990 recommendations of the International commission on radiological protection. Oxford [etc.]: Pergamon; 1991. VII, 201. (ICRP publication; vol. 60).
7. Jarvik JG, Comstock BA, James KT, Avins AL, Bresnahan BW, Deyo RA, et al. HHS Public Access. 2016;45(0 0):157–63.
8. Rupreht M. Slikovne preiskave v diagnostiki hrbtenice. 2012. 97–104 p.
9. Frank ED, Stears JG, Gray JE, Winkler NT, Hoffman AD. Use of the posteroanterior projection: A method of reducing X-ray exposure to specific radiosensitive organs. *Radiol Technol*. 1983;
10. Hart D, Wall B, Hillier M, Shrimpton P. HPA-CRCE-012 Frequency and collective dose for medical and dental X-ray examinations in the UK, 2008 [Internet]. Health Protection Agency HPA-CRCE-012. 2010. 1–52 p. Available from: <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Frequency+and+Collective+Dose+for+Medical+and+Dental+X-ray+Examinations+in+the+UK+,+2008#0>
11. Long BW, Frank ED, Ehrlich RA. Radiography Essentials for Limited Practice [Internet]. Elsevier; 2016. Available from: <https://books.google.si/books?id=E7jYjwEACAAJ>
12. Nic An Ghearr FA, Brennan PC. The PA projection of the abdomen: A dose reducing technique. *Radiography*. 1998;4(3):195–203.
13. European Union. Diagnostic Reference Levels in Thirty-six European Countries. Part 2/2 [Internet]. Radiation Protection N° 180. 2015. Available from: <https://ec.europa.eu/energy/sites/ener/files/documents/RP180 part2.pdf>
14. Medič M, Mekiš N. Diagnostične radiološke metode : skeletna diagnostika : učbenik za študente radiološke tehnologije. Ljubljana: Zdravstvena Fakulteta; 2018. 1–478 p.
15. Martin CJ. Optimisation in general radiography. *Biomed Imaging Interv J*. 2007;3(2).
16. Moilanen A, Kokko M, Pitkfinen M. Gonadal dose reduction in lumbar spine radiography. *Skeletal Radiol*. 1983;9(3):153–6.
17. Dilger R, Egan I, Hayek R. Effects of Focus Film Distance (FFD) variation on entrance testicular dose in lumbar-

- pelvic radiography. Vol. 6, Australasian chiropractic & osteopathy : journal of the Chiropractic & Osteopathic College of Australasia. 1997. p. 18–23.
18. Brennan PC, Nash M. Increasing FFD: An effective dose-reducing tool for lateral lumbar spine investigations. *Radiography*. 1998;4(4):251–9.
  19. Brennan PC, Madigan E. Lumbar spine radiology: analysis of the posteroanterior projection. *Eur Radiol*. 2000;10(7):1197–201.
  20. Fung KKL, Gilboy WB. "Anode heel effect" on patient dose in lumbar spine radiography. *Br J Radiol*. 2000;73(869):531–6.
  21. Doherty P, O'Leary D, Brennan PC. Do CEC guidelines under-utilise the full potential of increasing kVp as a dose-reducing tool? *Eur Radiol*. 2003;13(8):1992–9.
  22. Grondin Y, Matthews K, McEntee M, Rainford L, Casey M, Tonra M, et al. Dose-reducing strategies in combination offers substantial potential benefits to females requiring X-ray examination. *Radiat Prot Dosimetry*. 2004;108(2):123–32.
  23. Brindhavan A, AlKhalifah K, AlWathiqi G, AlOstath H. Effect of x-ray tube potential on image quality and patient dose for lumbar spine computed radiography examinations. *Australas Phys Eng Sci Med*. 2005;28(4):216–22.
  24. Geijer H, Persliden J. Varied tube potential with constant effective dose at lumbar spine radiography using a flat-panel digital detector. *Radiat Prot Dosimetry*. 2005;114(1–3):240–5.
  25. Clancy CL, O'Reilly G, Brennan PC, McEntee MF. The effect of patient shield position on gonad dose during lumbar spine radiography. *Radiography* [Internet]. 2010;16(2):131–5. Available from: <http://www.sciencedirect.com/science/article/pii/S1078817409000984>
  26. Olsson ML, Tingberg A, Mattsson S. A Phantom study showing the importance of compression in conventional diagnostic X-ray examinations. *Radiat Prot Dosimetry*. 2010;139(1–3):78–80.
  27. Davis AT, Hopkins SA. Optimisation of patient dose for the horizontal beam technique in lateral lumbar spine radiographic examinations. *Br J Radiol*. 2013;86(1027):2–5.
  28. Mekis N, Zontar D, Skrk D. The effect of breast shielding during lumbar spine radiography. *Radiol Oncol*. 2013;47(1):26–31.
  29. Chaparian A, Kanani A, Baghbanian M. Reduction of radiation risks in patients undergoing some X-ray examinations by using optimal projections: A Monte Carlo program-based mathematical calculation. *J Med Phys*. 2014;39(1):32–9.
  30. Davey E, England A. AP versus PA positioning in lumbar spine computed radiography: Image quality and individual organ doses. *Radiography* [Internet]. 2015;21(2):188–96. Available from: <http://dx.doi.org/10.1016/j.radi.2014.11.003>
  31. Ben-Shlomo A, Bartal G, Mosseri M, Avraham B, Leitner Y, Shabat S. Effective dose reduction in spine radiographic imaging by choosing the less radiation-sensitive side of the body. *Spine J* [Internet]. 2016;16(4):558–63. Available from: <http://dx.doi.org/10.1016/j.spinee.2015.12.012>
  32. Karami V, Zabihzadeh M. Beam Collimation during Lumbar Spine Radiography: A Retrospective Study. *J Biomed Phys Eng*. 2017;7(2):101–6.
  33. Robinson JB, Ali RM, Tootell AK, Hogg P. Does collimation affect patient dose in antero-posterior thoraco-lumbar spine? *Radiography* [Internet]. 2017;23(3):211–5. Available from: <http://dx.doi.org/10.1016/j.radi.2017.03.012>
  34. Shanahan MC. A pilot study investigating two dose reduction techniques for AP lumbar spine radiography using direct dosimetry and Projection VR. *Radiography* [Internet]. 2017;23(3):222–8. Available from: <http://dx.doi.org/10.1016/j.radi.2017.03.015>
  35. Alukic E, Skrk D, Mekis N. Comparison of anteroposterior and posteroanterior projection in lumbar spine radiography. *Radiol Oncol*. 2018;52(4):468–74.
  36. Green C, Karnati G, Thomson K, Subramanian A. Lumbar spine radiographs - Is it time for widespread adoption of posteroanterior projection? *Br J Radiol*. 2019;92(1103):1–6.
  37. Alukić E, Mekiš N. LUMBAR SPINE RADIOGRAPHY: LOWER ORGAN DOSE WITH THE USE OF PA PROJECTION. *Radiat Prot Dosimetry*. 2019;186(4):507–12.
  38. Pazanin A, Skrk D, O'Driscoll JC, McEntee MF, Mekis N. OPTIMAL COLLIMATION SIGNIFICANTLY IMPROVES LUMBAR. *Radiat Prot Dosimetry*. 2020;189(4):420–7.
  39. Peacock NE, Steward AL, Riley PJ. An evaluation of the effect of tube potential on clinical image quality using direct digital detectors for pelvis and lumbar spine radiographs. *J Med Radiat Sci*. 2020;260–8.
  40. Bellizzi A, Zarb F. Radiography Optimisation of the lateral lumbar spine projection using an air-gap technique. *Radiography* [Internet]. 2020;26(3):227–33. Available from: <https://doi.org/10.1016/j.radi.2019.12.008>
  41. Lai ZH, Sá dos Reis C, Sun Z. Effective dose and image optimisation of lateral lumbar spine radiography: a phantom study. *Eur Radiol Exp*. 2020;4(13).
  42. Tapiovaara M, Siiskonen T. A PCXMC - A Monte Carlo program for calculating patient doses in medical x-ray examinations. 2nd ed. 2008.