Analysis of the dose area product variable in radiography of the lumbar-sacral spine using a water phantom

Analiza zmiennych dose area product w radiografii kręgosłupa w odcinku lędźwiowo-krzyżowym z użyciem fantomu wodnego

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Abstract

Radiography is a commonly used diagnostic method. In order to detect many diseases, it is first-throw for radiologists and clinicians. In today's continuous technological progress, more attention is paid to the best possible diagnosis of patients with the least amount of burden on the body at the dose of ionizing radiation. Due to the exposure of the patient to radiation dose, each X-ray examination must be performed according to the ALARA principle (As Low As Reasonable Achievable), in other words, to provide good radiological quality with low radiation risk. This is why good knowledge and the use of any dependencies that affect both the dose received by the patient and the quality of the radiographs are of key importance here. In the presented work, the problem of these dependencies has been addressed based on the analysis of DAP dose area product from parameters such as anode voltage, filtration, collimation, volume. The analyzes were performed under simulated conditions of x-ray of the lumbar spine in the anterior- posterior projection using a water phantom. Analyzes have shown that the use of different anode voltage values and the collimation of the x-ray beam do not have a significant effect on the DAP value. On the other hand, beam filtration and reduction of the thickness of the examined object results in a significant reduction dose.

Streszczenie

Radiodiagnostyka jest powszechnie stosowaną metodą diagnostyczną. W celu wykrycia wielu schorzeń pozostaje ona dla radiologów i klinicystów metodą pierwszego rzutu. W dzisiejszej dobie ciągłego postępu technologicznego coraz większą uwagę przywiązuje się do jak najlepszej diagnostyki pacjentów z jednoczesnym najmniejszym obciążeniem ich organizmu na dawkę promieniowania jonizującego. Ze względu na narażenie pacjenta na dawkę promieniowania każde badanie rentgenowskie musi być wykonane w myśl zasady ALARA (*as low as reasonable achievable*), czyli krótko mówiąc tak, aby zapewnić dobrą jakość obrazów radiologicznych przy niskim ryzyku radiacyjnym. Dlatego też kluczową rolę odgrywa tutaj dobra znajomość oraz wykorzystanie wszelkich zależności, które mają wpływ zarówno na dawkę, jaką otrzymuje pacjent, jak również jakość powstałych radiogramów. W przedstawionej pracy zajęto się problemem wspomnianych zależności na podstawie analizy wartości obszaru dawki DAP od takich parametrów, jak: napięcie anodowe, filtracja, kolimacja, objętość. Analizy dokonano w symulowanych warunkach rentgenodiagnostyki odcinka lędźwiowego kręgosłupa w projekcji anterior-posterior przy wykorzystaniu fantomu wodnego. Analizy wykazały, iż zastosowanie różnych wartości napięcia anodowego oraz zmiana kolimacji wiązki promieniowania x nie mają istotnego wpływu na wartość obszaru dawki (DAP). Natomiast filtracja wiązki oraz zmniejszenie grubości obiektu badanego powoduje znaczącą redukcję wartości DAP.

Słowa kluczowe:

radiografia, promieniowanie jonizujące, produkt obszaru dawki, fantom wodny, kręgosłup w odcinku lędźwiowo-krzyżowym

Introduction

A classic X-ray image is the cheapest, most accessible, and thus the most commonly performed imaging examination. At the end of the 20th century in Switzerland, lumbar-sacral spine radiography was the third most frequently used radiographic examination (39 per 1000 inhabitants per year) [1]. In the United Kingdom, in the first decade of the 21st century, the exam occupied the ninth position in rankings of the 22 most frequently performed studies using ionizing radiation [2]. Also in Poland, lumbar-sacral spine radiography is an examination that is often commissioned. In 2009, 70 exposures per 1000 inhabitants of the Mazovian province were made [3]. A significant percentage of referrals are painful back pain. In Australia, this is the third cause (5.8%) of radiological examinations by family physicians [4]. In this group of patients, degenerative changes are most often diagnosed on the basis of radiography [5].

Regardless of the obvious differences in the frequency of studies between countries and even individual centers in a given country, as a result of the specificity of the patients being diagnosed, each radiogram must have a specific image quality. However, the quality cannot be considered without the patient's radiation exposure context. In this case, a good practice in radiography is the ALARA principle (As Low As Reasonably Achievable) [6,7]. Radiation dose in radiography is a compromise between optimum image and radiation exposure. The awareness of the people performing the exposures in terms of the impact of individual variables of imaging on the dose and quality is most important.

During radiographic diagnosis, radiation exposure monitoring can be performed by registering and evaluating the dose area product (DAP). DAP is a very good indicator as it takes into account the dose and surface area. The dose area product is measured by the x-ray ionization chamber, which does not require any additional personnel effort [8,9].

The objective of the study was to analyze the dose area product in lumbar spine radiography using a water phantom.

Materials and methods

150 x-ray water phantom images were taken in simulated X-rays of the lumbar spine in the anterior-posterior projection. A phantom glass was used: $x = 60$ cm, $y = 30$ cm, $h = 31$ cm. The study was carried out at the Department of Radiology at the University Hospital in Bialystok, using SIEMENS AXIOM ARISTOS. Analysis was done for the variables (Table 1). Fixed imaging parameters:

1. Anti-scatter grid f(o) = 115
2. Focus-film distance (FFD) = 115 cm
3. Focus 1.0
4. Speed 400

The dose area product in [μGy·cm^2] was read from the DICOM protocol. STATISTICA 12.0 from StatSoft was used for statistical analysis of the collected data. Comparisons of measurements, made under various conditions, were made using non-parametric U-Mann Whitney and Kruskal-Wallis tests along with post-hoc tests. Statistically significant results were found at $p < 0.05$.

Results

Analyses showed that as the anode voltage increases, the average DAP value decreases (Figure 1). The average DAP value at 90kV decreases by 24% compared with 81kV. The observed differences in DAP measurements at different anode voltage values are not statistically significant ($p = 0.85$) (Table 2).

Application of filtration reduces DAP (Table 3). Using 0.2 mm Cu, the mean dose (Me = 19.90) is more statistically significant ($p < 0.001$) than without filter (Me = 40.00). Similarly, when using 0.01 Cu, a smaller mean dose (Me = 25.95) is observed than without the use of a filter, with the differences appearing at the limit of statistical significance ($p = 0.055$).

In the study, the higher collimation field is associated with an average higher DAP measurement, as shown in Table 4. The performed analyses do not show that the observed differences were statistically significant ($p = 0.17$).

The average DAP measurement for the smallest tested phantom volume is just 7.95 (Me) and for the largest volume it is equal to 77.80 (Me). In general, for larger volumes, significantly higher DAP measurements are observed than for smaller ones. The significance of the differences is shown in Table 5.

Discussion

Pain in the lumbar-sacral spine has become an outbreak of the 21st century. The problem concerns young and old people, although the causes in both groups may be different. Often, pain limits and even prevents functioning, which affects quality of life [10,11]. In order to diagnose and decide on the treatment of spine disorders, patients are referred for radiography. Although the x-ray image is characterized by low specificity and sensitivity, especially in the case of acute back pain, as indicated by the study, it

Fig. 1.
Analysis of the dependence of the DAP on the voltage anode X-ray tube

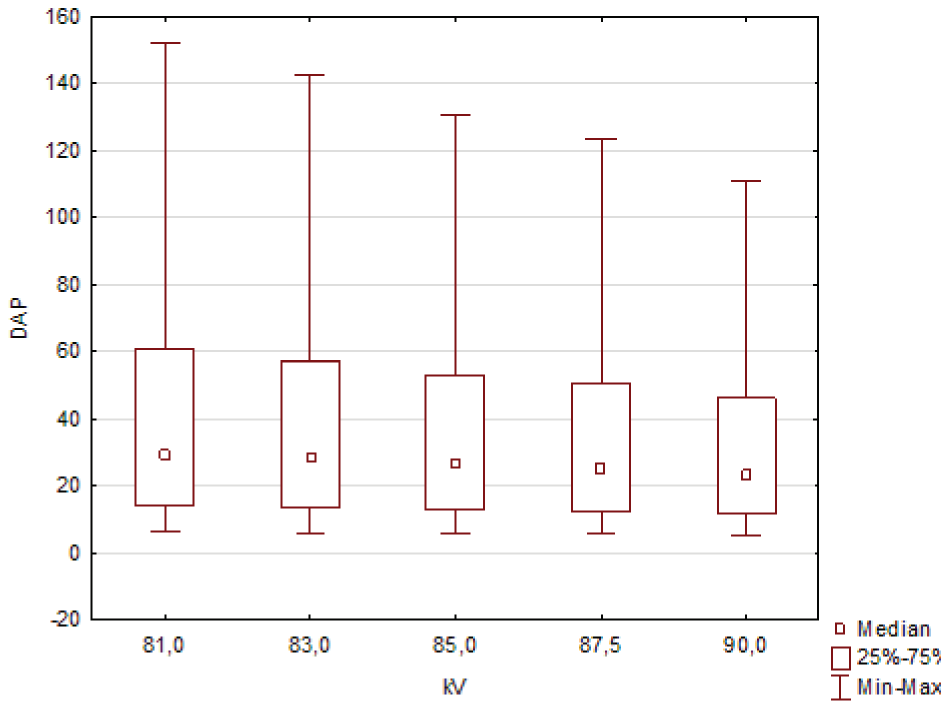

Table 1.
Exposition parameters of radiography of phantom

Parameter	Value
X-ray anode potential	81 kV 83 kV 85 kV 87.5 kV 90 kV
Filtering	0 mm 0.1 mm Cu 0.2 mm Cu
Collimation	588 cm^2 (14 x 42 cm) 756 cm^2 (18 x 42 cm)
Volume of water phantom	18000 cm^3 (h = 10 cm) 23400 cm^3 (h = 13 cm) 28800 cm^3 (h = 16 cm) 34200 cm^3 (h = 19 cm) 39600 cm^3 (h = 22 cm)

Table 2.
Analysis of the effect of the X-ray anode potential on DAP

Anode potential [kV]	DAP [μGy·cm²]						
	Min.	Max.	Mean	Me	Q_1	Q_3	p
81	6.30	152.00	42.61	29.65	14.20	60.90	0.85
83	6.10	142.80	40.38	28.35	13.80	57.50	
85	5.80	130.80	37.33	26.55	12.90	53.30	
87.5	5.60	123.70	35.68	25.45	12.50	50.80	
90	5.40	111.30	32.57	23.50	11.60	46.30	

DAP – Dose Area Product; Me – median, Min. – lowest value, Max. – maximum value, Q1 –lower quartile, Q3 – upper quartile

Table 3.
Analysis of the effect of filtering on DAP

Filtering [mm Cu]	DAP [μGy·cm²]						
	Min.	Max.	Mean	Me	Q_1	Q_3	p
0 (I)	10.40	152.00	53.00	40.00	19.80	73.80	I-II: $p = 0.055$ I-III: $p < 0.001$ II-III: $p = 0.367$
0.1 (II)	6.90	96.50	34.10	25.95	12.90	47.60	
0.2 (III)	5.40	72.70	26.04	19.90	10.00	36.20	

DAP – Dose Area Product; Me- median, Min.- lowest value, Max.- maximum value, Q1 - lower quartile, Q3- upper quartile

Table 4.
Analysis of radiation beam collimation field relative to DAP value

Collimation field [cm²]	DAP [μGy·cm²]						
	Min.	Max.	Mean	Me	Q1	Q3	p
588 (14 x 42 cm)	5.40	127.60	34.21	23.50	11.60	50.80	0.17
756 (18 x 42 cm)	6.70	152.00	41.21	28.80	14.30	60.20	

DAP – Dose Area Product; Me – median, Min. – lowest value, Max. – maximum value, Q1 – lower quartile, Q3 – upper quartile

Table 5.
Analysis based on the volume of the water phantom on the value of DAP

Volume [cm^3]	DAP [μGy·cm^2]						
	Min.	Max.	Mean	Me	Q_1	Q_3	p
18000 (I)	5.4	15.4	9.17	7.95	6.90	11.40	I-II: $p = 0.205$
23400 (II)	9.00	27.10	15.95	14.25	11.90	19.80	I-III: $p < 0.001$
28800 (III)	16.10	50.10	29.05	25.95	21.20	36.40	I-IV: $p < 0.001$
34200 (IV)	26.50	84.80	48.40	43.50	34.70	61.00	I-V: $p < 0.001$
39600 (V)	46.30	152.00	85.99	77.80	60.90	109.70	II-III: $p = 0.045$
							II-IV: $p < 0.001$
							II-V: $p < 0.001$
							III-IV: $p = 0.127$
							III-V: $p < 0.001$
							IV-V: $p = 0.163$

DAP – Dose Area Product; Me – median, Min. – lowest value, Max. – maximum value, Q1 – lower quartile, Q3 – upper quartile

is commonly used in clinical assessment [12]. Due to the exposure of the patient to the radiation dose, each X-ray examination must be done taking into account optimization principles, that is to ensure good quality images with low radiation risk [6,7]. Knowledge of the relationships that have the greatest impact on the patient's dose and skillful use play an important role in this process.

Anode voltage determines the penetration of the original x-ray beam. In the case of higher voltages, the dose area product will have lower values [13]. As recommended in the standard procedure, lumbar spine radiography should be performed at 75-95 kV [14]. In Kim et al., X-ray images in Korea were performed at 60-95 kV anode voltage [15]. In contrast, in a 2016 study in Southwestern Nigeria, radiography was performed in the range of 60 to 117 kV [16]. In Iran, the average anode voltage is 70kV, with a range of 50-93 [17]. The high variability of imaging parameters in the analyzed literature may be related to several factors. It seems that the leading factor is body mass index, because it depends on the volume of the test object to individually select the anode potential.

Low-energy (soft) radiation coming out of the X-ray tube does not reach the image detector, which means that it does not have any involvement in image formation and only contributes to the high radiation dose received by the subject. Proper filtration is therefore essential for patient safety [18]. The absorption filter inserted into the radiation beam changes the beam spectrum, limiting the share of the lowest energy radiation. The most commonly used filter materials are aluminum (Al) and copper (Cu) [7,19]. Self-analysis confirms reduction of the dose area product with additional filtration in lumbar spine radiography.

Geijer et al. analyzed the effects on the effective dose. The study shows that the optimum solution is to change the sensitivity of the detector from 400 to 800 at high filtration values (4.5 mm Al) [20]. Behrman also examined the effect of varying the thickness of filtration at constant sensitivity. Changing the filter from 2.5 mm Al to 4.0 mm Al is a reduction of the average dermal input dose by almost 20% [21].

Significant reductions in DAP in the test can be combined with copper filtration. Copper filters are about 10% more efficient in beam hardening than aluminum filters [22]. Compared with aluminum filtration, copper filters exhibit higher photoelectric absorption than the Compton Effect. Hence, their high efficiency in classical X-ray diagnostics, where the X-ray interactions with matter are dominant in the X-ray tube range, is the photo-effect [23].

The dose area product is strongly associated with the primary beam field. As the collimation area increases, the value of DAP increases [19]. In the study, a small dose increase was observed between the larger and the smaller field, which may be due to the use of a water phantom for testing. Radiography of patients with an increased radiation beam field also increases the volume of the diagnosed area. Consequently, it should always be sought that the collimation is as small as possible and sufficient for the clinical interpretation of the patient [24].

In a clinical area, the attenuation and absorption of X-rays is characterized by considerable variability, determined by the type of structure and the patient's body weight. DAP in lumbar spine radiography in obese patients is higher than in patients with normal weight [25]. It must be remembered that a change in the thickness of the examined object by 4 cm is a double attenuation, thus penetration of the beam is also halved. In such a situation, elongation of the exposure time ensures the appropriate dose of radiation reaching the detector, which is reflected in the higher dose area product [13].

The Alshamari study indicates that obese patient exposure can be three times higher (1.5 vs. 0.5 Gy·cm^2) [26]. In a water phantom study, the medium through which the radiation beam passes is homogeneous. The effect of DAP growth is also noticeable. In the case of patient diagnostics, the amount of dose received also influences the effective dose of tissue or objects in the beam field for example steel implants in diagnostic radiography [13].

In the UK, the average DAP value of X-ray imaging in the anterior-posterior (AP) projection obtained by digital imaging is 1410 mGy·cm^2 [27]. A similar value of 1400 mGy·cm^2 was obtained by researchers from Southwestern Nigeria [17]. In Saudi Arabia, higher doses were observed (2440 mGy·cm^2), with an anode voltage of 80 kV [28]. Extremely high DAP differentiation in different diagnostic centers indicates the need for uniform radiographic techniques to provide optimum protection for the patient from excessive radiation dose [29]. Since January 2015, Poland has implemented obligatory standards in radiography [14]. Several years ago, reference levels were introduced in clinical practice. In the case of projection of lumbar spine AP it is 3200 mGy·cm^2 [30]. The expected benefit is reducing patient exposure [31]. Realization of this task is possible only by understanding how individual exposure variables affect the dose.

Conclusions

In a water phantom study, simulated lumbar spine radiography revealed:

1. The use of different anode voltage values does not significantly affect the DAP value.
2. The use of 0.2 mm Cu filtration significantly reduces the DAP value.
3. Changing the collimation of the X-ray beam does not significantly affect the DAP value.
4. With the reduction of the phantom thickness, the DAP value is considerably reduced.

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