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# ASSESSING THE DOSE VALUES RECEIVED BY PATIENTS DURING CONVENTIONAL RADIOGRAPHY X-RAY EXAMINATIONS AND THE TECHNICAL CONDITION OF THE EQUIPMENT USED FOR THIS PURPOSE

## OCENA WIELKOŚCI DAWEK OTRZYMYWANYCH PRZEZ PACJENTÓW PODCZAS OGÓLNODIAGNOSTYCZNYCH BADAŃ RENTGENOWSKICH ORAZ OCENA STANU TECHNICZNEGO STOSOWANEGO SPRZĘTU

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**Abstract**

**Background**: X-ray examination is associated with patient exposure to ionizing radiation. Dose values depend on the type of medical procedure used, the X-ray unit technical condition and exposure conditions selected. The aim of this study was to determine the dose value received by patients during certain conventional radiography X-ray examinations and to assess the technical condition of medical equipment used for this purpose. **Material and Methods:** The study covered the total number of 118 conventional diagnostic X-ray units located in the Masovian Voivodeship. The methodology used to assess the conventional diagnostic X-ray unit technical condition and the measurement of the radiation dose rate received by patients are based on test procedures developed by the Department of Radiation Protection and Radiobiology of the National Institute of Public Health – National Institute of Hygiene (Warszawa, Poland) accredited for compliance with PN-EN 17025 standard by the Polish Centre for Accreditation. **Results:** It was found that 84.7% of X-ray units fully meet the criteria set out in the Polish legislation regarding the safe use of ionizing radiation in medicine, while 15.3% of the units do not meet some of them. The broadest dose value range was recorded for adult patients. Particularly, during lateral (LAT) lumbar spine radiography the recorded entrance surface dose (ESD) values ranged from 283.5 to 7827 μGy (mean: 2183.3 μGy). **Conclusions:** It is absolutely necessary to constantly monitor the technical condition of all X-ray units, because it affects population exposure to ionizing radiation. Furthermore, it is essential to raise radiographers' awareness of the effects that ionizing radiation exposure can have on the human body. Med Pr 2014;65(6):715–721

**Key words:** conventional radiology, entrance surface dose, ESD, X-ray medical procedures

**Streszczenie**

**Wstęp:** Wykonywanie badań rentgenowskich wiąże się z narażeniem pacjenta na działanie promieniowania jonizującego. Wielkość tego narażenia zależna jest od wykonywanej procedury medycznej, stanu technicznego aparatu rentgenowskiego i dobranych warunków ekspozycji. Celem niniejszych badań było określenie wielkości dawek, na jakie narażeni są pacjenci podczas wybranych ogólnodiagnostycznych badań rentgenowskich oraz ocena stanu technicznego używanej aparatury medycznej. **Materiał i metody**: Badaniami objęto łącznie 118 ogólnodiagnostycznych aparatów rentgenowskich, zlokalizowanych na terenie województwa mazowieckiego. Metodyka badań dotycząca oceny ich stanu technicznego i pomiaru dawek otrzymywanych przez pacjentów oparta została na opracowanych w Zakładzie Higieny Radiacyjnej i Radiobiologii (Narodowy Instytut Zdrowia Publicznego – Państwowy Zakład Higieny) procedurach badawczych, akredytowanych na zgodność z normą PN-EN 17025 przez Polskie Centrum Akredytacji. **Wyniki:** W wyniku przeprowadzonych badań stwierdzono, że 84,7% aparatów w pełni spełnia kryteria określone w polskim ustawodawstwie dotyczącym zasad bezpiecznego stosowania promieniowania jonizującego w medycynie, a 15,3% nie spełnia części z nich. Największą rozpiętość otrzymywanych dawek zaobserwowano u pacjentów dorosłych. W szczególności dotyczy to radiografii kręgosłupa lędźwiowego w projekcji bocznej (lateral lumbar spine radiography – LAT). Mierzone w trakcie tej procedury wartości wejściowej dawki powierzchniowej (entrance surface dose – ESD) znajdowały się w przedziale 283,5–7827 μGy (średnia: 2183,3 μGy). **Wnioski:** Niezbędne jest stałe monitorowanie stanu technicznego aparatów rentgenowskich, który wpływa na wielkość narażenia badanych na promieniowanie jonizujące. Konieczne jest też podnoszenie świadomości osób wykonujących badania w zakresie wpływu promieniowania rentgenowskiego na organizm człowieka. Med. Pr. 2014;65(6):715–721

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**Słowa kluczowe:** radiologia ogólna, wejściowa dawka powierzchniowa, ESD, rentgenowskie procedury medyczne

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## INTRODUCTION

X-ray medical examinations are currently very common. In many cases, they provide the basis for further treatment. Their distinctive feature is that they may be done quickly (which is necessary e.g., in the case of traffic accident injuries where you need to obtain results as soon as possible) and at relatively low cost. To carry out such examinations correctly, it is necessary to select suitable exposure conditions based on the medical procedure, the patient body constitution, and the X-ray image recording method (1–3). The factors mentioned above and the X-ray unit technical condition have a significant impact on the size of patient exposure to ionizing radiation. X-ray tomography and interventional radiology examinations have the largest impact, while the smallest one comes from X-ray dental examinations (4).

Patient exposure to ionizing radiation during X-ray examinations carries the risk of inducing additional cancers. It is estimated that, each year, from several dozens to several thousand patients develop a different kind of cancer in each country where X-ray medical examinations are performed (5).

The aim of this study was to assess the dose value received by patients during certain conventional radiography X-ray examinations and to assess the technical condition of medical equipment used for this purpose. Examinations were conducted in the Masovian Voivodeship due to the fact that it is the biggest voivodeship in Poland regarding the number of X-ray units and inhabitants. According to the authors, the performed research structure and location of the X-ray units (hospitals, clinics, private medical centers) are similar throughout the country. Research on the assessment of the number and the kind of X-ray medical procedures in the Masovian Voivodeship has been described in more details in the following paper (6).

## MATERIAL AND METHODS

At the outset of the study, it was necessary to determine the number of X-ray units used in the Masovian Voivodeship. For this purpose the MZ-52 report of the Main Statistical Office (prepared annually by the Voivodeship Sanitary-Epidemiological Station in Warszawa, Poland) was used. Basing on the report, it was found that there are 563 conventional diagnostic X-ray units used in the voivodeship located in hospitals, clinics, private medical centers.

Selection of X-ray rooms with regard to their territorial location, the type of public health entity and the type of unit was based on preliminary (pilot) studies. The data obtained from the preliminary test allowed to determine the necessary number of X-ray units that should be examined (63 X-ray units). The correctness of the selection of the research sample was estimated using the dependence given by Hellwig (7,8). It was necessary to carry out the estimation of the standard deviation and the maximum error of estimate (tolerance) was determined on the basis of selected parameters of the X-ray units.

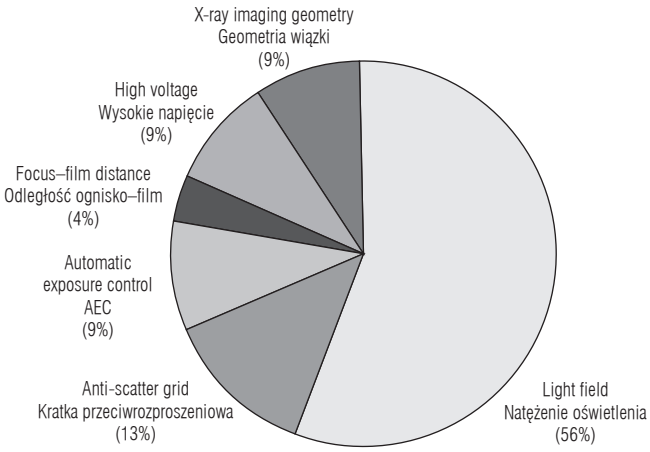
Out of the 563 X-ray units located in the Masovian Voivodeship, 118 X-ray units were selected for tests. The selection took into account their location (city, country) and the status of the entity (hospital, clinic, private medical center). These units were located in 56 X-ray rooms. The number of X-ray units covered by the study was almost twice higher than required (63 X-ray units).

Conventional diagnostic X-ray unit technical condition assessment methodology was based on the research procedure developed by the Department of Radiation Protection and Radiobiology of the National Institute of Public Health – National Institute of Hygiene. The procedure had been accredited by the Polish Centre for Accreditation in Warszawa, Poland (Certificate No. AB-509). The scope of research was in compliance with the applicable regulation of the Ministry of Health (2). This document is a mandatory legal act in Poland in line with the European Union legislation. The procedure included inspecting high voltage generator operation, exposure time consistency, half value layer thickness, X-ray tube output, radiation beam geometry, illumination intensity of the field simulating the radiation field, anti-scatter grid operation, AEC system operation, total beam filtration size, X-ray focal

spot size and the distance between the X-ray focal spot and the image recorder (6,8,9). Each of these parameters was subject to a separate assessment. A parameter value was deemed acceptable if it had not exceed the tolerance limits specified in Annex 6 to the regulation mentioned above (2).

The entrance surface dose (ESD) received by patients during routine examinations was also measured. For this purpose, PTW Diados E and Unfors RaySafe Xi dosimeters were used. A dose detector was placed on a body phantom. The phantom was made of PMMA (polymethyl methacrylate). The backscatter factor was taken into consideration while measuring dose values.

In each X-ray room, X-ray technicians were asked to recreate examination conditions based on patient medical records of adults and children (aged 5 and 10). Each time the technician's task was to select exposure conditions (kV, mAs) and the distance between the X-ray focal spot and the body phantom. The ESD was recorded for the most frequent medical procedures performed in the Masovian Voivodeship (6,9). The procedures included chest radiography in PA and LAT projections, skull radiography in AP and LAT projections, as well as spine, abdomen and pelvis radiography.




AEC – automatic exposure control / automatyczna kontrola ekspozycji.

**Fig. 1.** Negatively evaluated technical parameters of conventional diagnostic X-ray units
**Ryc. 1.** Negatywnie ocenione parametry techniczne ogólnodiagnostycznych aparatów rentgenowskich

## RESULTS

Conventional diagnostic X-ray unit technical condition tests included 118 units (20.96% of all X-ray units used in the Masovian Voivodeship). It was found that 84.7% of the tested units fully meet the criteria set out in the Polish legislation, while 15.3% of the units meet only some of them. As regards the X-ray units that failed to fully meet the criteria, it was found that non-compliance was most often attributed to too low illumination intensity of the field simulating the radiation field (56%), improper operation of the anti-scatter grid (13%), improper operation of the AEC system (9%), high voltage inconsistency (9%), failure to maintain the radiation beam geometry (9%), and the inaccurate reading of the distance between the X-ray focal spot and the image recorder (4%). For some units, more than 1 technical issue was found (4.2%). Results concerning the most frequent abnormalities are presented in Figure 1.

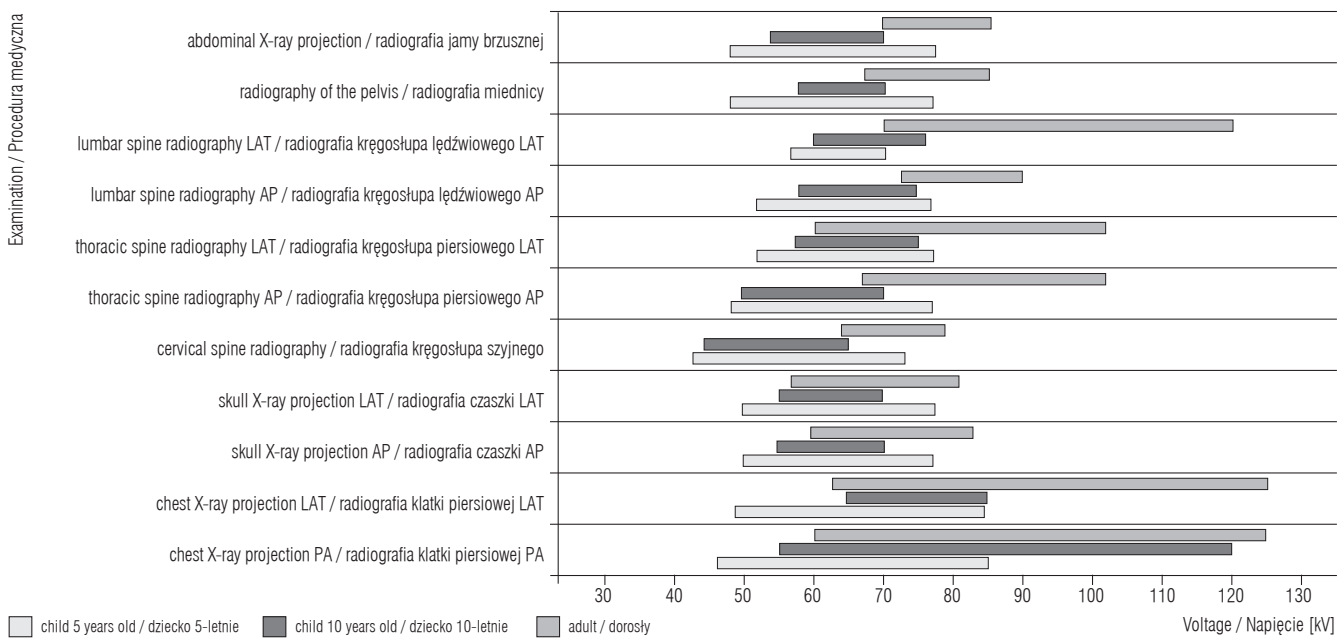
Subsequently, dose values received by patients were examined. First of all, data related to X-ray exposure conditions selected by X-ray technicians was collected (based on medical records), including selected high voltage values (kV) and current exposure time values (I×t) for the most commonly applied medical procedures targeting adults and children (aged 5 and 10). In total, data for 1570 exposure conditions was collected. High voltage values are shown in Figure 2.

Results indicate that the selected high voltage value range for the number of X-ray procedures is broad. In the case of adult PA chest radiography, it was found that high voltage ranged from 60 to 125 kV (with the average value of 101.0 kV). In the case of adult LAT lumbar spine radiography, it was found that the selected high voltage value range was also broad (70 to 120 kV with the average value of 89.1 kV). Exposure conditions selected by X-ray technicians for children aged 10 are also of a broad range. For instance, the selected high voltage values for PA chest radiography ranged from 55 to 120 kV (with an average value of 74.5 kV). The narrowest high voltage ranges for the same X-ray procedure were found for children aged 5. The selected high voltage values for LAT lumbar spine radiography ranged from 57 to 70 kV (with an average value of 62.4 kV). Current exposure time value (I×t) selected by X-ray technicians depended on the selected medical procedure, selected high voltage and the patient age. The highest current exposure time values were found during adult examinations (even 289 mAs during the LAT chest radiography). The lowest current exposure time values were found during examinations of children aged 5. The highest recorded current exposure time value for children aged 5 was 20.3 mAs

**Table 1.** Entrance surface dose (ESD) received by patients during conventional radiography X-ray examinations
**Tabela 1.** Wejściowe dawki powierzchniowe (ESD) otrzymywane przez pacjentów w trakcie ogólnodiagnostycznych badań rentgenowskich

| Examination<br>Procedura medyczna | ESD [μGy] | | | | | |
|---|---|---|---|---|---|---|
| | child 5 years old<br>dziecko 5-letnie | | child 10 years old<br>dziecko 10-letnie | | adult<br>dorosły | |
| | R | M | R | M | R | M |
| Chest X-ray, AP projection / Radiografia klatki piersiowej, projekcja AP | 62.5–196.6 | 111.7 | 71.2–223.1 | 139.2 | 122.7–1 076.5 | 317.5 |
| Chest X-ray, LAT projection / Radiografia klatki piersiowej, projekcja LAT | 124.9–407.9 | 212.7 | 185.1–394.5 | 297.0 | 265.5–1 107.9 | 565.8 |
| Skull X-ray, AP projection / Radiografia czaszki, projekcja AP | 101.9–338.0 | 184.5 | 156.0–491.0 | 280.0 | 203.9–2 195.5 | 894.4 |
| Skull X-ray, LAT projection / Radiografia czaszki, projekcja LAT | 79.0–350.8 | 167.5 | 126.1–285.7 | 206.5 | 211.8–1 499.0 | 694.4 |
| Cervical spine radiography / Radiografia kręgosłupa szyjnego | 21.9–121.9 | 59.0 | 40.7–120.5 | 67.6 | 184.4–1 165.7 | 625.8 |
| Thoracic spine radiography, AP/PA projection / Radiografia kręgosłupa piersiowego, projekcja AP/PA | 36.2–164.4 | 89.2 | 91.6–173.9 | 121.7 | 258.3–4 908.7 | 1 541.6 |
| Thoracic spine radiography, LAT projection / Radiografia kręgosłupa piersiowego, projekcja LAT | 55.4–206.2 | 110.2 | 110.3–271.1 | 180.8 | 283.5–7 827.0 | 2 183.3 |
| Lumbar spine radiography, AP projection / Radiografia kręgosłupa lędźwiowego, projekcja AP | 68.0–197.2 | 124.4 | 99.2–379.2 | 202.9 | 516.8–10 062.0 | 2 685.7 |
| Lumbarspine radiography, LAT projection / Radiografia kręgosłupa lędźwiowego, projekcja LAT | 124.5–305.5 | 179.9 | 170.7–520.8 | 322.6 | 946.9–14 477.5 | 4 265.7 |
| Radiography of the pelvis / Radiografia miednicy | 88.9–437.3 | 249.6 | 242.4–436.7 | 349.2 | 625.7–4 916.3 | 1 853.6 |
| Radiography of the abdomen / Radiografia jamy brzusznej | 88.9–453.4 | 218.3 | 259.8–569.4 | 449.9 | 763.1–4 414.4 | 2 294.1 |

AP – anteroposterior / przednio-tylna, LAT – lateral / boczna, PA – posteroanterior / tylno-przednia.
R – range / zakres, M – mean / średnia.




Abbreviations as in Table 1 / Skróty jak w tabeli 1.

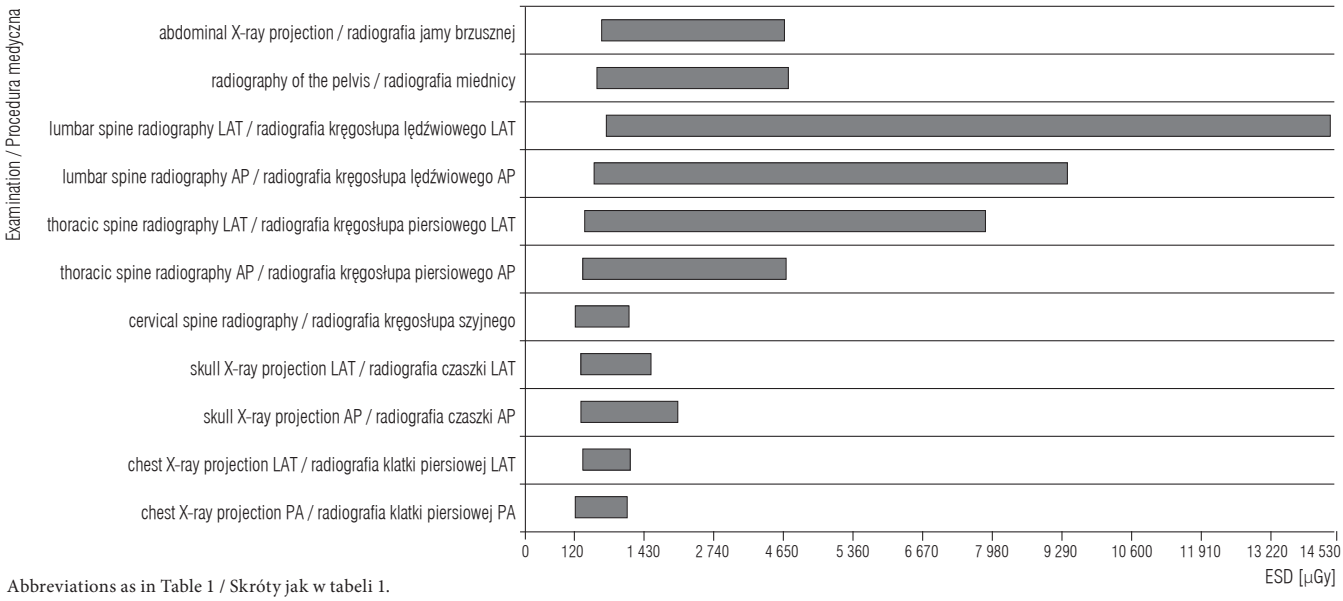
**Fig. 2.** Selecting the high voltage value during conventional radiography X-ray examinations
**Ryc. 2.** Wartości wysokiego napięcia wybierane podczas wykonywania ogólnodiagnostycznych badań rentgenowskich

(during the LAT lumbar spine radiography). Entrance surface dose values received by patients during X-ray examinations are set out in Table 1.

It was found that there are even a few dozen differences in dose values received by patients during the same medical procedure. The broadest distribution of dose values was observed in the case of adult patients. Particularly, during the LAT lumbar spine radiography the recorded entrance surface dose values for the procedure ranged from 283.5 to 7827.0 μGy (with the average value of 2183.3 μGy). During the adult AP lumbar spine radiography and the adult AP thoracic spine radiography a broad distribution of dose values was also found. The highest recorded ESD/lowest recorded ESD ratio for these procedures reached 20. The recorded adult ESD ranges are set out in Figure 3.

## DISCUSSION

The results indicate that the technical condition of the majority of conventional diagnostic X-ray units is satisfactory, but efforts should be made to improve it, since 15.3% of the units do not fully meet the criteria set out in the Polish legislation (2). Illumination intensity of the field simulating the radiation field was the main non-compliant X-ray parameter (56% of all found inconsistencies). It is worth mentioning that the parameter does not have any direct impact on the dose values received by patients during examinations. However, it makes it more difficult for X-ray technicians to perform medical exposures, since it is hard to adjust the radiation field size, particularly in X-ray rooms with good lighting. Other non-compliant parameters (i.e., improper AEC system operation and related unjustified increase of the current exposure time value) already have a direct impact on the dose values received by patients during examinations. Another aspect that should be taken into consideration is related to the negative impact of the improper X-ray operation on the X-ray image quality. For instance, improper anti-scatter grid operation may result in artifacts in X-ray images. Consequently, it may make correct diagnosis even more difficult, and in extreme cases, it may be necessary to repeat the whole examination and to re-expose the patient to the ionizing radiation.




Abbreviations as in Table 1 / Skróty jak w tabeli 1.

**Fig. 3.** Range of the entrance surface dose (ESD) received by adult patients during selected X-ray medical procedures
**Ryc. 3.** Zakres wejściowych dawek powierzchniowych (ESD) otrzymywanych przez pacjentów dorosłych podczas wybranych rentgenowskich procedur medycznych

It was observed that, for the patients aged 5 and 10, there was no such broad distribution of ESD values. The highest one was recorder for children aged 5 during the cervical spine radiography. The ESD range was from 21.9 to 121.9 μGy (with the average value of 59.0 μGy). The narrowest ESD range was observed during the pelvis radiography of children aged 10. The ESD range was from 242.4 to 436.7 μGy (with the average value of 349.2 μGy). The highest recorded ESD/lowest recorded ESD ratio for the same procedures for children aged 5 and 10 reached 5.6.

Results indicate that the technical condition of conventional diagnostic X-ray units is satisfactory, but efforts should be made to improve it, since 15.3% of the units do not fully meet the criteria set out in the Polish legislation (2). This is achieved mainly due to the replacement of old equipment with modern designs. The currently used X-ray units differ from those used 10 or 15 years ago (10). Due to the continuous replacement of X-ray units, the quality of X-ray images is getting better and better. The image recording method has also changed. More and more frequently X-ray centers resign from the use of analog X-ray film to the advantage of digital recording. This should also lead to X-ray images quality improvement.

The ESD value distribution observed for the same medical procedures during children and adult examinations (the ESD value distribution for adults was even broader than for children) cannot be attributed only to the X-ray unit technical condition or the patient anatomic structure. Basing on the exposure condition selected by X-ray technicians, it can be noticed that they do not always follow recommendations applicable to X-ray examinations. For some procedures, recommendations related to exposure parameters (high voltage) or focal spot size selection has been set out (1). For instance, during adult PA chest radiography the recommended high voltage value is 125 kV, while values selected by X-ray technicians ranged from 60 to 125 kV (with the average value of 101 kV). Therefore, it seems justified to introduce some uniform X-ray examination procedures in X-ray rooms to be based on model procedures. It is quite important, since it was found that reference levels set out in the Polish legislation (2) were more than once exceeded, i.e. the reference level for the adult AP chest radiography is 0.3 mGy, while values recorded ranged from 0.123 to 1.077 mGy (with an average value of 0.32 mGy).

Basing on the obtained entrance surface dose (ESD) values received by adults and children patients, the average effective dose has been estimated using Monte Carlo simulation and considering the appropriate tissue weighting factor (11,12).

Children aged 5 received the highest effective dose during the pelvis radiography (average effective dose value: 39.0 μSv; range: 12.0–70.3 μSv). Children aged 10 received the highest effective dose during the stomach radiography (average effective dose value: 68.6 μSv; range: 40.9–87.0 μSv). Adults are exposed to the highest effective dose during the AP lumbar spine radiography (average effective dose value: 437.2 μSv; range: 83.8–1704.7 μSv). The values recorded do not differ from those estimated in other European countries, including the United Kingdom and France (4,13). For instance, in the UK, the average effective dose value received during the AP lumbar spine radiography was 389 μSv.

## CONCLUSIONS

The results obtained confirm the need to control the quality of the physical parameters of X-ray units used in Poland in order to detect malfunctions that pose a threat to patients' health or life.

It is essential to constantly monitor the situation regarding the technical condition of X-ray units which affects the size of the population exposure to ionizing radiation.

The recorded entrance surface dose values and estimated effective dose values do not differ from the values recorded in other European countries.

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