Individual doses in screening mammography examinations performed with digital equipment in Poland

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Summary

Background: The aim of this study was the estimation of individual doses for women participating in the mammography screening program in Poland, examined with digital systems.

Material/Methods: Materials for this study included data obtained from 1800 exposures performed with the use of 9 different mammography units with digital systems. Exposure conditions (breast thickness after compression, high voltage, mAs value, the material of the anode and additional filter) were recorded during mammography screening examinations conducted for over one year in Poland. The collected data were used to determine individual doses in accordance with the method, which uses conversion factors for air kerma to the absorbed dose in the glandular tissue. The entrance air kerma for compressed breast exposure was determined on the basis of the measurements of the air kerma for the high-voltage value at which the exposure was performed, assuming a linear air kerma dependence on the tube load.

Results: Individual doses established in 9 mammography facilities ranged from 0.40 mGy to 11.48 mGy for CR (computed radiography) systems and from 0.36 mGy to 5.80 mGy for DR (digital radiography) systems. The maximum value of the individual doses for CR systems was about 98% higher than for DR systems. The values of compressed breast thickness ranged from 2.0 cm to 7.6 cm for CR systems and from 2.1 cm to 11.4 cm for DR systems. The glandularity of breasts was from 9% to 100% for CR systems and from 3% to 97% for DR systems. The mean glandularity of breasts was 47% for CR systems and 29% for DR systems.

Conclusions: One of the criteria for evaluating the suitability of digital systems in breast cancer screening in Poland should be the systematic evaluation of individual doses. In Poland, it is necessary to implement standardized methods of optimization of the exposure parameters for reducing individual doses to a minimum necessary to maintain the image quality.

Key words: individual dose • digital mammography • computed radiography

Background

"Polish National Breast Cancer Early Detection Program for Women Aged from 50 to 69" has been carried out in Poland since 2006. Most of the mammography units used during mammography screening examinations have been equipped with film detectors. Other mammography units have been equipped with digital detectors.

The number of digital systems (DR – Digital Radiography and CR – Computed Radiography) used in mammography screening examinations in Poland constantly increases, and therefore exposure to X-rays of women examined with the use of these systems should not be overlooked. Many authors have presented the results of the estimation of doses for women investigated with mammography units with a full-field digital detector [1–6]. They showed that the average glandular dose did not exceed 2.0 mGy per exposure in any of the cases, which is a very satisfactory result. However, the results of some authors indicate that the doses received by women examined with mammography units equipped with digital detectors are higher than with systems using a film-screen detector [2], and others that the trend is reversed [3,4,6,7]. In general, the doses are higher for CR systems than for mammography units equipped with film detectors [8]. The diversity of the results led the authors of this article to analyze individual doses for women participating in the mammography screening program in Poland, examined with digital systems.

So far, Poland has had no legal regulations concerning quality control of mammography units equipped with digital systems. However, under the coordination of Regional Coordinating Centers (RCC), doses received by women participating in screening were estimated. Regional Coordinating Centers are administrative structures established by the Ministry of Health for organization and supervision of the implementation of the mammography screening program. The principal center is the Central Coordinating Center (CCC) based in The Maria Skłodowska-Curie Memorial Cancer Center and Institute of Oncology in Warsaw. The parameters of the exposures of women and the results of the measurements needed to estimate the doses received by women were sent to the CCC. The calculations of an average glandular dose for a single exposure (referred to later in the text as *individual dose*) were carried out by the physicists at the CCC. In this way, individual doses were determined for women investigated by mammography units with CR and DR systems. It should be noted that at present, individual doses are not estimated in Poland at all.

Table 1. The list of mammography units with the DR system (letters from A to D stand for manufactures of mammography units).

Number of the unit	Material of image detector/ manufacturer	Combination of anode/filter used during exposures
1	Amorphous silicon/ A	Mo/Mo; Mo/Rh; Rh/Rh
2	Amorphous selenium (a – Se)/ B	Mo/Mo; Mo/Rh
3	Amorphous selenium (a – Se)/ C	W/Rh
4	Amorphous selenium (a – Se)/ B	Mo/Mo; Mo/Rh
5	Amorphous selenium (a – Se)/ D	W/Rh

Table 2. The list of mammography units with the CR system (letters from E to H stand for manufactures of mammography units and letters from I to K stand for manufactures of the CR system).

Number of the unit	Manufacturer of mammography unit/ manufacturer of CR system	Combination of anode/ filter used during exposures
6	E/ I	Mo/Mo
7	F/ J	Mo/Mo; Mo/Rh
8	G/ I	Mo/Mo
9	H/ K	Mo/Mo; Mo/Rh

Table 3. Limiting values for average glandular doses for various thicknesses of PMMA phantoms and the corresponding equivalent breast thicknesses and glandularity values.

Thickness of PMMA [cm]	Equivalent breast thickness [cm]	Glandularity of equivalent breast [%]	Maximum average glandular doses to equivalent breasts [mGy]	
			Acceptable level	Achievable level
2.0	2.1	97	<1.0	<0.6
3.0	3.2	67	<1.5	<1.0
4.0	4.5	41	<2.0	<1.6
4.5	5.3	29	<2.5	<2.0
5.0	6.0	20	<3.0	<2.4
6.0	7.5	9	<4.5	<3.6
7.0	9.0	4	<6.5	<5.1

Material and Methods

Materials for this study included data from 1800 exposures performed with the use of 9 different mammography units (9 series with 200 exposures each) in Poland. Among those nine mammography units, five were equipped with DR systems and four with CR systems (Tables 1, 2). Data from the mammography units were collected during mammography screening examinations for one year.

In each exposure of each woman, the following parameters were collected: breast thickness after compression, high-voltage value, tube load value, the material of the anode and additional filter. Moreover, the half-value layer (HVL) measurements were made for the values of high voltage used during these exposures. These measurements were carried out using a Piranha multimeter manufactured by RTI Electronics AB (type: 305, accuracy: ±5%) and aluminium filters manufactured by Gammex (≥99.9% purity; six 0.10-mm-thick pieces). These measurements were done by physicists from RCC during an inspection of mammography units carried out by RCC.

The collected data were used to determine individual doses for each exposure in accordance with the method published by Dance [10]. This method uses conversion factors for air kerma to the absorbed dose in the glandular tissue. Conversion factors were determined by using the Monte Carlo method and taking into account the X-ray quality (measured by means of the half-value layer, the material of the anode and additional filtration), the thickness of the breast after compression and the glandularity of the breast. The entrance air kerma for compressed breast exposure was determined on the basis of the measurements of the air kerma for the high-voltage value at which the exposure was performed, assuming a linear air kerma dependence on the tube load. Individual doses were calculated according to the following formula, proposed by Dance:

$$D = K \cdot g \cdot c \cdot s \text{ [10]}$$

K – entrance surface air kerma (without backscatter) at the upper surface of the breast, referred to later in the text as *ESAK*, g – factor dependent on the thickness of the compressed breast and half-value layer [10], c – factor dependent on the glandularity of the breast and half-value layer [10], s – factor dependent on the X-ray spectrum [10].

The limiting values of individual doses for different values of breast thickness after compression and of glandularity were presented in the „European guidelines for quality assurance in breast cancer screening and diagnosis. Fourth

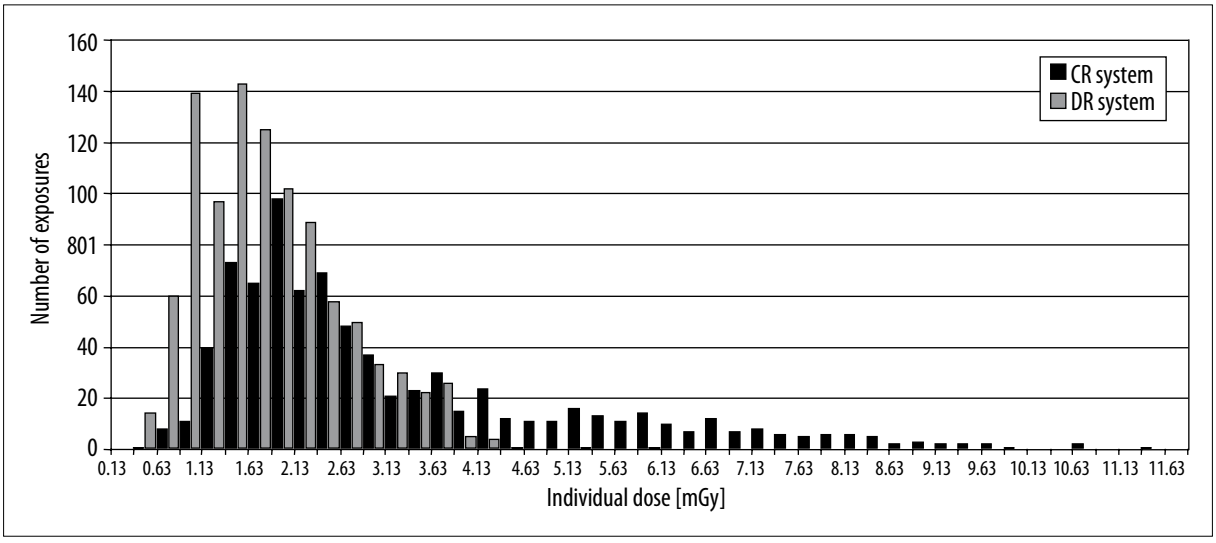

Figure 1. A histogram of individual doses per exposure for women examined with the use of four mammography units equipped with the CR system (the minimum value: 0.40 mGy; the maximum value: 11.48 mGy; the mean value: 3.12 mGy) and with the use of five mammography units equipped with the DR system (the minimum value: 0.36 mGy; the maximum value: 5.80 mGy; the mean value: 1.74 mGy).

edition" [9] (Table 3). There were two levels given in the document mentioned above: acceptable and achievable one, which is more restrictive than the acceptable level. These values are constant for all mammography systems.

Estimated individual doses for each exposure were compared to the levels mentioned above. To determine the individual dose limit for each breast thickness after compression, the second-degree polynomial, based on data contained in Table 3, was fitted. For the acceptable level, the polynomial was as follows: $0.091 \cdot \chi^2 - 0.2326 \cdot \chi + 1.1786$. For the achievable level, the polynomial was as follows: $0.059 \cdot \chi^2 - 0.012 \cdot \chi + 0.402$ In both cases, χ stands for breast thickness after compression in cm, and the ratio R^2 was higher than 0.99.

The total uncertainty associated with individual doses was estimated at 14% in accordance with the „Patient dose in digital mammography" [1]. In this work, the total uncertainty included several factors:

- the uncertainties associated with ESAK calculations: 6%,
- the uncertainty in "g" factor tabulated by Dance: 10%,
- the uncertainty in "g" factor associated with errors in HVL measurements: 4%,
- the uncertainty in "g" factor associated with errors in breast thickness measurements: 1%,
- the maximum uncertainty in "s" factor tabulated by Dance: 4%,
- the uncertainty in "s" factor associated with errors in the glandularity: 5% for absolute variations of breast glandularity of ±10%.

Results and Discussion

Figure 1 shows the distribution of individual doses per exposure for women examined with the use of mammography units, equipped with digital systems, divided into DR and CR systems. A light colour in the histogram indicates doses from the DR system, and the dark colour – from the CR system, ranging from 0.36 mGy to 5.80 mGy and from

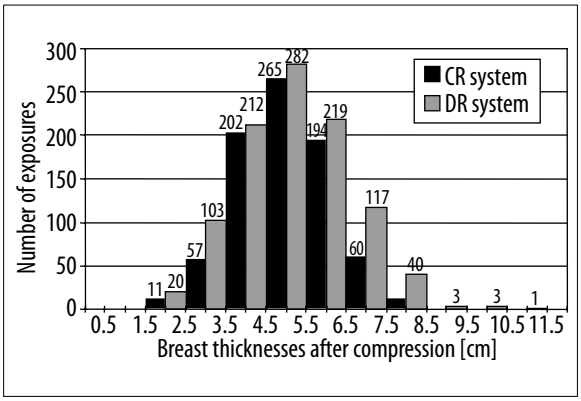

Figure 2. A histogram of breast thicknesses after compression for women examined with the use of four mammography units equipped with the CR system (the minimum value: 2.0 cm; the maximum value: 7.6 cm; the mean value: 4.5 cm) and with the use of five mammography units equipped with the DR system (the minimum value: 2.1 cm; the maximum value: 11.4 cm; the mean value: 5.6 cm).

0.40 mGy to 11.48 mGy, respectively. The average values of doses were 1.74 mGy (DR systems) and 3.12 mGy (CR systems). The data show that women examined with the use of mammography units equipped with CR systems received average doses higher by approximately 79% than women examined with DR systems. The maximum value of individual doses for CR systems was about 98% higher than for DR systems. The obtained results confirm the data presented in the equipment report by NHSBSP [8].

Because the age of women was similar in all cases (50–69 years), the main factor affecting the amount of dose was the thickness of the breast after compression and the glandularity. Figure 2 shows the minimum, maximum and average values of breast thickness after compression for women examined with the use of mammography units equipped with DR and CR systems. The average value of breast thickness for DR systems was about 24% higher than for

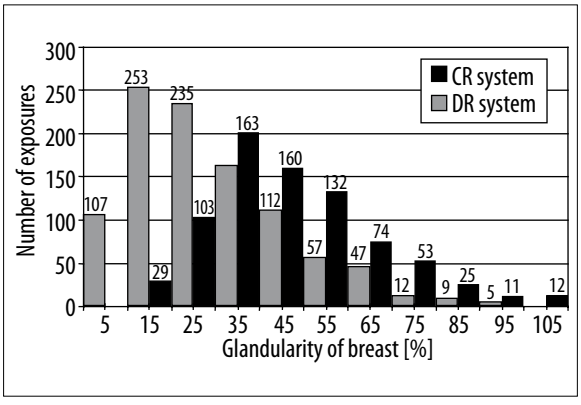

Figure 3. A histogram of breast glandularity for women examined with the use of four mammography units equipped with the CR system (the minimum value: 9%; the maximum value: 100%; the mean value: 47%) and with the use of five mammography units equipped with the DR system (the minimum value: 3%; the maximum value: 97%; the mean value: 29%).

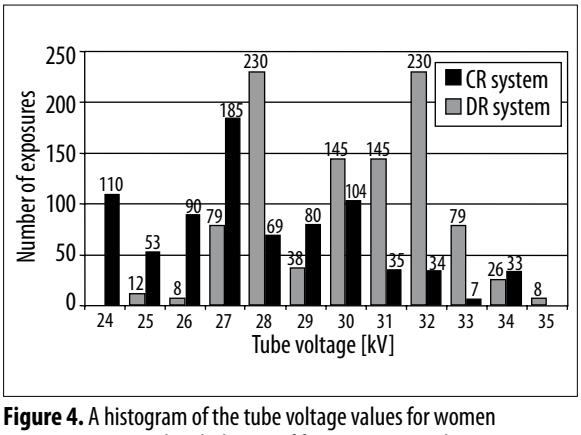

Figure 4. A histogram of the tube voltage values for women examined with the use of four mammography units equipped with the CR system (the minimum value: 24 kV; the maximum value: 34 kV; the most frequent value: 27 kV) and with the use of five mammography units equipped with the DR system (the minimum value: 25 kV; the maximum value: 35 kV).

CR systems and the range of breast thicknesses was wider for DR systems. Figure 3 shows the minimum, maximum and average values of breast glandularity for women examined with the use of mammography units equipped with DR and CR systems. The average value of breast glandularity was higher for mammography units with CR systems than for those with DR systems. It is known that the dose is higher for thicker breasts and for breasts with low content of glandular tissue. Therefore, individual doses received by women examined with the use of mammography units equipped with DR systems should be higher than with CR systems. In fact, the situation is reversed, as shown in Figure 1.

All imaging examinations in nine mammography facilities were performed using the settings recommended by the manufacturers of the mammography units. Those settings were constant for all examined women in each mammography facility. The distribution of the tube voltage values is shown in Figure 4. The range of tube voltage for two types of systems was almost the same. The most frequent value of the tube voltage for CR systems was 27 kV. For DR systems, there was no such value and there were two values (28 kV and 32 kV) which appeared with the same frequency. As shown in Table 4, combinations of anode/filter used during exposures were different for those two types of systems as well. For CR systems, none of the exposures was made with a combination of Rh/Rh and W/Rh. For DR systems, on the other hand, 16.8% and 40.0% of exposures (respectively) were made with these combinations of anode and filter. The combination of Mo/Mo was used in 70.0% of exposures for CR systems and in 23.2% of exposures for DR systems. The last combination of anode/filter (i.e. Mo/Rh) was used in 30.0% of exposures for CR systems and 20.0% of exposures for DR systems. As shown in Figure 5, the mean value of the tube load for CR systems was about 48% higher than for DR systems. The range of tube load values for CR systems was wider than for DR systems and it was 203 mAs and about 160 mAs, respectively. The differences in tube load values for CR and DR systems resulted from different values of breast thickness after compression and different combinations of anode/filter used during exposures.

Table 5 shows the minimum, maximum and average values of individual doses received by women examined with

Table 4. Combination of anode/filter used during exposures for DR and CR systems.

Combination of anode/filter used during exposures	Percentage of exposures for all DR systems	Percentage of exposures for all CR systems
Mo/Mo	23.2%	70.0%
Mo/Rh	20.0%	30.0%
Rh/Rh	16.8%	0.0%
W/Rh	40.0%	0.0%

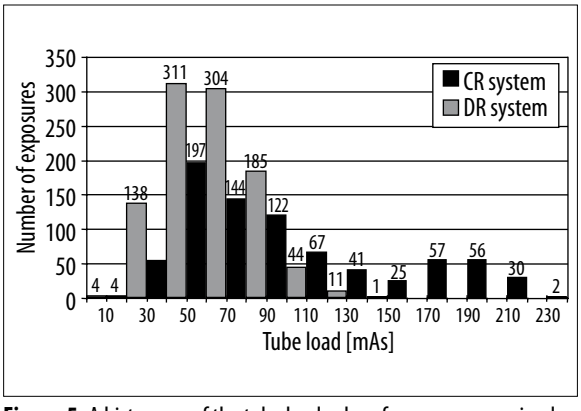

Figure 5. A histogram of the tube load values for women examined with the use of four mammography units equipped with the CR system (the minimum value: 10 mAs; the maximum value: 213 mAs; the mean value: 95 mAs) and with the use of five mammography units equipped with the DR system (the minimum value: 12 mAs; the maximum value: 172 mAs; the mean value: 64 mAs).

Table 5. Individual doses received by women examined with the use of different mammography units and the percentage of exposures not exceeding the acceptable and achievable level of individual dose.

Number of the mammograpy unit	System	Individual dose [mGy]			The percentage of exposures not exceeding	
		The minimum value	The maximum value	The mean value	Acceptable level [%]	Achievable level [%]
1	DR	0.97	5.80	2.06	80	53
2	DR	1.20	5.01	2.54	77	57
3	DR	0.78	4.26	1.74	100	97
4	DR	0.37	3.76	1.54	98	93
5	DR	0.34	1.85	0.84	100	100
6	CR	0.58	6.38	2.06	77	24
7	CR	0.40	5.53	2.67	25	10
8	CR	0.81	4.90	1.92	43	16
9	CR	2.21	11.48	5.81	0	0

the use of mammography units (listed in Tables 1, 2). For each group of women, the percentages of exposures that reached the acceptable and achievable levels of individual doses were also given. As indicated in the summary of the results, individual doses for each mammography unit varied, even for systems of the same manufacturer (mammography unit number 2 and 4). The average values of individual doses for all digital systems used for mammography screening examinations in Poland ranged from 0.84 mGy to 5.81 mGy, and thus the highest average value was about seven times higher than the lowest one.

Individual doses for women examined with the use of different mammography units did not exceed acceptable level in almost one hundred percent of exposures only for three DR systems (mammography unit number 3 and 5: both with a tungsten anode and mammography unit number 4 with a molybdenum anode). For all CR systems, the highest percentage of exposures not exceeding the acceptable level was only 77% (mammography unit number 6). Individual doses reached the acceptable levels for two mammography units with the DR system in 80% and 77% of exposures and for three units with the CR system in 43%, 25% and 0% of exposures. Individual doses did not exceed the achievable level in almost one hundred percent of exposures for three mammography units with DR systems (the same for which the acceptable level of individual dose was reached in almost one hundred percent of exposures). However, for other mammography units, a significant decrease in the percentage of exposures was recorded, at which individual doses did not exceed the achievable level. There was only one mammography unit (number 9) with the CR system, for which none of two hundred exposures reach the acceptable level or the achievable level.

Conclusions

One of the criteria for evaluating the suitability of digital systems in breast cancer screening in Poland (besides quality control tests of the appropriate technical and physical quality of the equipment and of the appropriate image quality) should be the systematic evaluation of individual doses.

The obtained results indicate that the use of digital mammography systems even of the same manufacturer (even if the requirements of quality control of equipment are fulfilled, which guarantees a suitable image quality) may be associated with very different individual doses. Therefore, it is necessary to implement in Poland standardized methods of optimization of the exposure parameters for reducing individual doses to a minimum necessary to maintain the image quality.

A conclusion that the X-ray tube with a tungsten anode and rhodium filter for a digital detector based on amorphous selenium is optimal for digital mammography units in terms of individual doses should not be generalized, because systems with molybdenum anodes can be calibrated so that the doses received by women would be the same as for systems with tungsten anodes.

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