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Evaluation of Doses and Image Quality in Mammography with Screen-Film, CR, and DR Detectors – Application of the ACR Phantom

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Background:

Different methods of image quality evaluation are routinely used for analogue and digital mammography systems in Poland. In the present study, image quality for several screen-film (SF), computed radiography (CR), and fully digital (DR) mammography systems was compared directly with the use of the ACR mammography accreditation phantom.

Material/Methods:

Image quality and mean glandular doses were measured and compared for 47 mammography systems in the Mazovia Voivodeship in Poland, including 26 SF systems, 12 CR systems, and 9 DR systems. The mean glandular dose for the breast simulated by 4.5 cm of PMMA was calculated with methods described in the "European guidelines for quality assurance in breast cancer screening and diagnosis". Visibility of the structures in the image (fibers, microcalcifications, and masses) was evaluated with the mammographic accreditation ACR phantom.

Results:

Image quality for DR systems was significantly higher than for SF and CR systems. Several SF systems failed to pass the image quality tests because of artifacts. The doses were within acceptable limits for all of the systems, but the doses for the CR systems were significantly higher than for the SF and DR systems.

Conclusions:

The best image quality, at a reasonably low dose, was observed for the DR systems. The CR systems are capable of obtaining the same image quality as the SF systems, but only at a significantly higher dose. The ACR phantom can be routinely used to evaluate image quality for all types of mammographic systems.

MeSH Keywords:

Mammography • Quality Control • Radiation Dosage

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Background

Patient doses and image quality are the major concerns in mammography. This is especially true in breast cancer screening, where the large majority of the women examined is healthy, and small lesions are looked for. Currently, three types of image detector are used in mammography: screen-film (SF), computed radiography (CR), and digital radiography (DR), with a growing number of digital (CR and DR) systems [1]. It is known that CR mammography detectors have worse physical characteristics than DR [2], and are not as efficient as DR systems in the detection of microcalcifications in breasts [3]. The DR systems are known to

perform as well as SF systems in breast cancer screening [4–6]. For CR systems either a lower cancer detection rate is observed than for SF [4], or the same cancer detection rate but at a higher dose [5].

Until recently, regular tests of image quality had been officially required in Poland only for SF units [7]. Tests of image quality are carried out for all types of systems only in the case of those mammography units which are used for breast cancer screening [1,8]. It is known that CR systems in Poland fail the quality control tests most often and yield the highest doses [1,9]. However, even for breast cancer screening, there is no data available that would allow

direct comparison of image quality between analogue (SF) and digital (CR and DR) systems in Poland. The scope of the tests is based on the European protocol for quality control in mammography, which specifies different methods of image quality assessment for analogue systems and for digital systems [10,11]. For SF systems, relatively simple phantoms are used for visual tests of spatial resolution and visibility of low contrast structures. For CR and DR systems, different phantoms and a different methodology of image quality assessment are used (automated analysis of CDMAM phantom images) [12]. Unfortunately, results of tests with different phantoms are hard to compare. In theory, CDMAM methodology could be applied to SF systems, but that would be very time-consuming. It should also be noted that the CDMAM phantom has been criticized, because of significant differences between results obtained with different phantoms of the same type [13], so it should not be a phantom of choice for a comparison between different systems.

According to recent regulation of the Ministry of Health [14], the situation has changed. A new test of image quality is required for all CR and DR systems (but not for SF systems), including those not involved in breast cancer screening. The visibility of fibers, groups of microcalcifications, and masses (tumors) should be evaluated visually in the phantom image. While the phantom type is not identified by name in the regulations, its description corresponds with the ACR (American College of Radiology) mammography accreditation phantom. The phantom was originally designed for SF systems, and limiting values for the phantom represent a very low challenge for state-of-the-art DR systems [15]. According to some authors, the phantom is an adequate tool for the assessment of image quality in digital mammography [16], but according to others it is not so [17]. Despite its potential limitations, the phantom is currently used for all types of mammography systems in the process of accreditation by the ACR [18].

In the present study, image quality for several SF, CR, and DR mammography systems was directly compared with the use of the ACR mammography accreditation phantom. The data obtained, together with the results of measurements of doses performed with the European protocol [10,11], were used to compare the performance of the three groups of mammography systems.

Material and Methods

The measurements of mean glandular doses and of image quality were performed from August to October 2013, during the yearly audits of mammography systems used for breast cancer screening in the Mazovia Voivodeship in Poland. The measurements were carried out for 47 mammography systems, including:

- 26 systems with screen-film (SF) detectors (mammography units manufactured by GE, Lorad, Siemens, Planmed, Philips, IMS Giotto),
- 12 systems with computed radiography (CR) detectors (Carestream HR-M3, Carestream SNP-M1, Agfa MM 3.0, Fuji CH HR-VI, Konica CP1M200),
- 9 systems with digital radiography (DR) detectors (Siemens Mammomat Inspiration, Hologic Selenia, Hologic Selenia Dimensions, IMS Giotto).

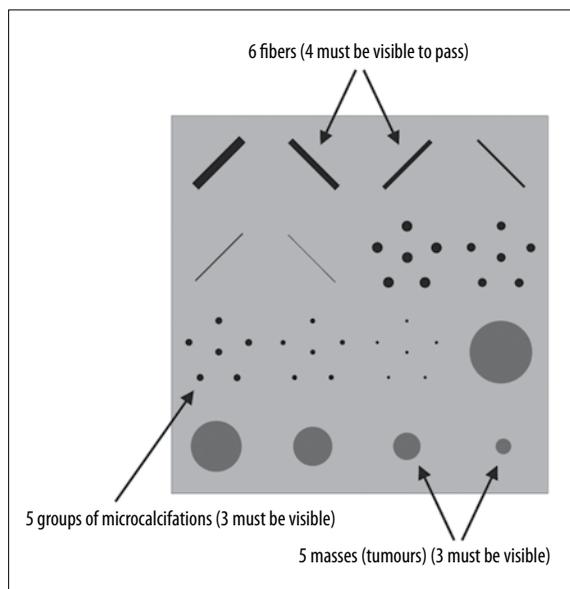


Figure 1. Scheme of the ACR mammography accreditation phantom.

The average glandular dose for the breast simulated by 4.5 cm of PMMA was measured and calculated for each system using methods described in the European guidelines [10,11]. The air kerma (K) was measured with a Piranha multimeter (manufactured by RTI Electronics AB) for the same exposure parameters, which would be chosen by the automatic exposure control (AEC) system for 4.5 cm PMMA phantom. The average glandular dose was calculated as:

$$\text{MGD} = K \cdot g \cdot c \cdot s$$

where g , c , and s are factors characterizing beam quality and the breast. The doses were compared with the maximum acceptable dose level (2.5 mGy) and with the achievable level (2.0 mGy) [10,11].

Image quality was evaluated with the ACR mammography accreditation phantom (Gammex Model 156). The phantom is made of acrylic, and simulates a compressed breast with a thickness of 4.2 cm and a 50%/50% composition of adipose and glandular tissue. The phantom has several structures of known shapes and dimensions, that simulate fibers, groups of microcalcifications, and masses (Figure 1). A mammographic image of the phantom was obtained on each mammography system in clinical mode, that is with the use of the AEC system. The images were reviewed by medical physicists on a viewing box (analogue images) or on medical displays (digital images) intended for mammography. All the images were scored according to the rules outlined in the "ACR Mammography Quality Control Manual" [19], which can be summarized as follows:

- +1 point for each visible structure;
- +1/2 of point for each partly visible structure;
- -1 point (penalty) for each false structure, e.g. false group of microcalcifications caused by dust between the film and the intensifying screen;
- at least 4 points for fibers, 3 points for microcalcifications, and 3 points for masses must be obtained by the system to pass the test.

Table 1. Average results of dose measurements, evaluation of image quality (ACR phantom score), and ratio between phantom score and dose for three categories of systems. Numbers in brackets represent results not corrected for presence of artifacts (with no penalty for false structures).

System category	Average glandular dose [mGy]	ACR phantom score				Phantom score/dose [mGy ⁻¹]
		Fibers	Microcalc.	Masses	Total	
SF	1.27	4.4	2.7 (3.0)	4.1	11.2 (11.5)	9.1 (9.3)
CR	1.79	4.8	3.3	3.8	11.8	6.9
DR	1.30	5.3	3.8	4.4	13.4	10.9

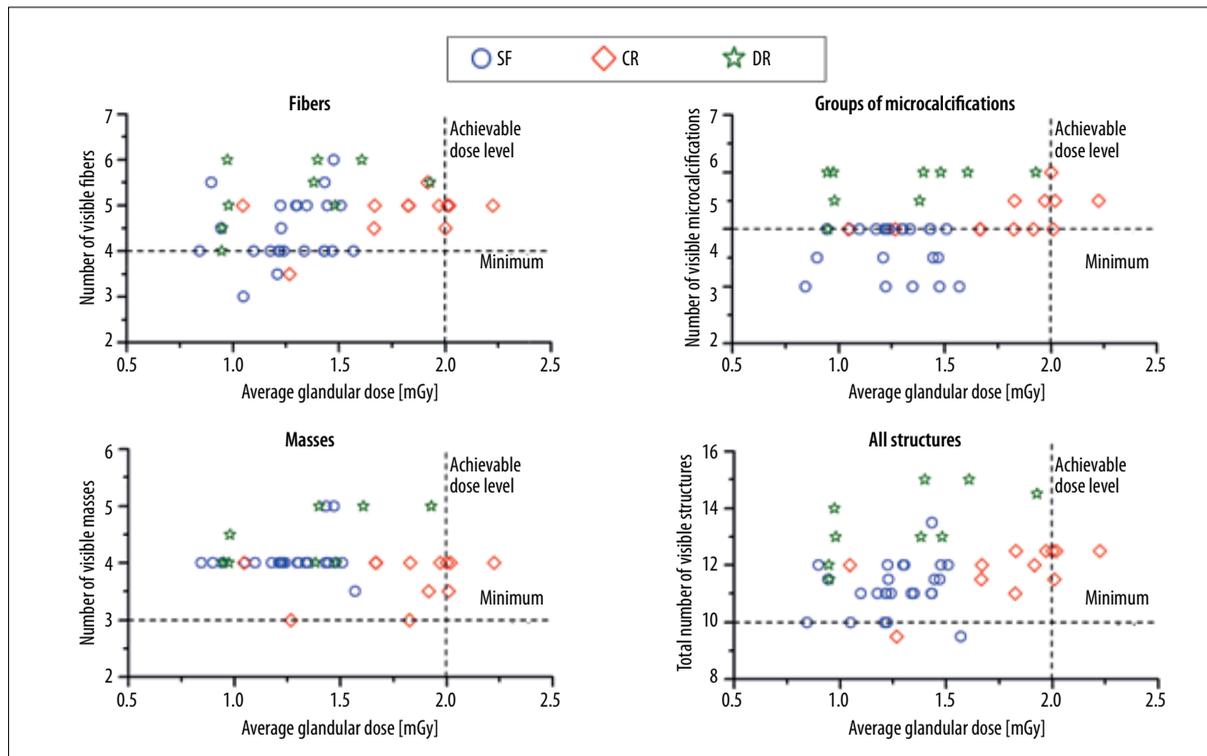


Figure 2. Visibility of structures in the image of the ACR phantom vs. average glandular dose. Minimum acceptable levels of image quality are marked with horizontal dashed lines; achievable dose level (2 mGy) is marked with a vertical dashed line.

The scoring rules described above are similar, but not identical to those outlined in recent Polish regulations for CR and DR systems. According to the regulations, all fibers with diameters equal to or larger than 0.75 mm must be visible, all microcalcifications with diameters of 0.32 mm and larger, and all masses with a thickness of 0.75 mm and larger [14]. These requirements translate to a visibility of 4 fibers, 3 microcalcifications and 3 masses as outlined by the ACR [18,19]. However, Polish regulations do not require scoring with points, and do not mention penalty points for artifacts.

Finally, the ratio between the total number of visible structures in ACR phantom image and the average glandular dose for a breast simulated with 4.5 cm of PMMA was calculated for each system. The ratio, expressed as the number of structures per mGy, can be treated as a measure of “dose efficiency” of a system. The results obtained for the three groups of mammography systems have been

compared. The t-test was used to compare the doses. The Mann-Whitney test was used to compare the phantom score, and the ratio between phantom score and the doses. The differences were treated as significant for $p < 0.05$.

Results

The average results for the three groups of systems are presented in Table 1. The detailed results are presented in Figures 2 and 3. The maximum acceptable dose level (2.5 mGy) was not exceeded in any of the cases, but the achievable dose level (2.0 mGy) was exceeded for 3 of 12 CR systems. The doses for CR systems were significantly higher than the doses for SF and DR systems. Dose differences between DR and SF systems were not significant.

All of the DR systems passed the image quality test, while 9 of 26 SF systems and 1 of 12 CR systems did not pass it. The main reason for the relatively large ratio of failure for

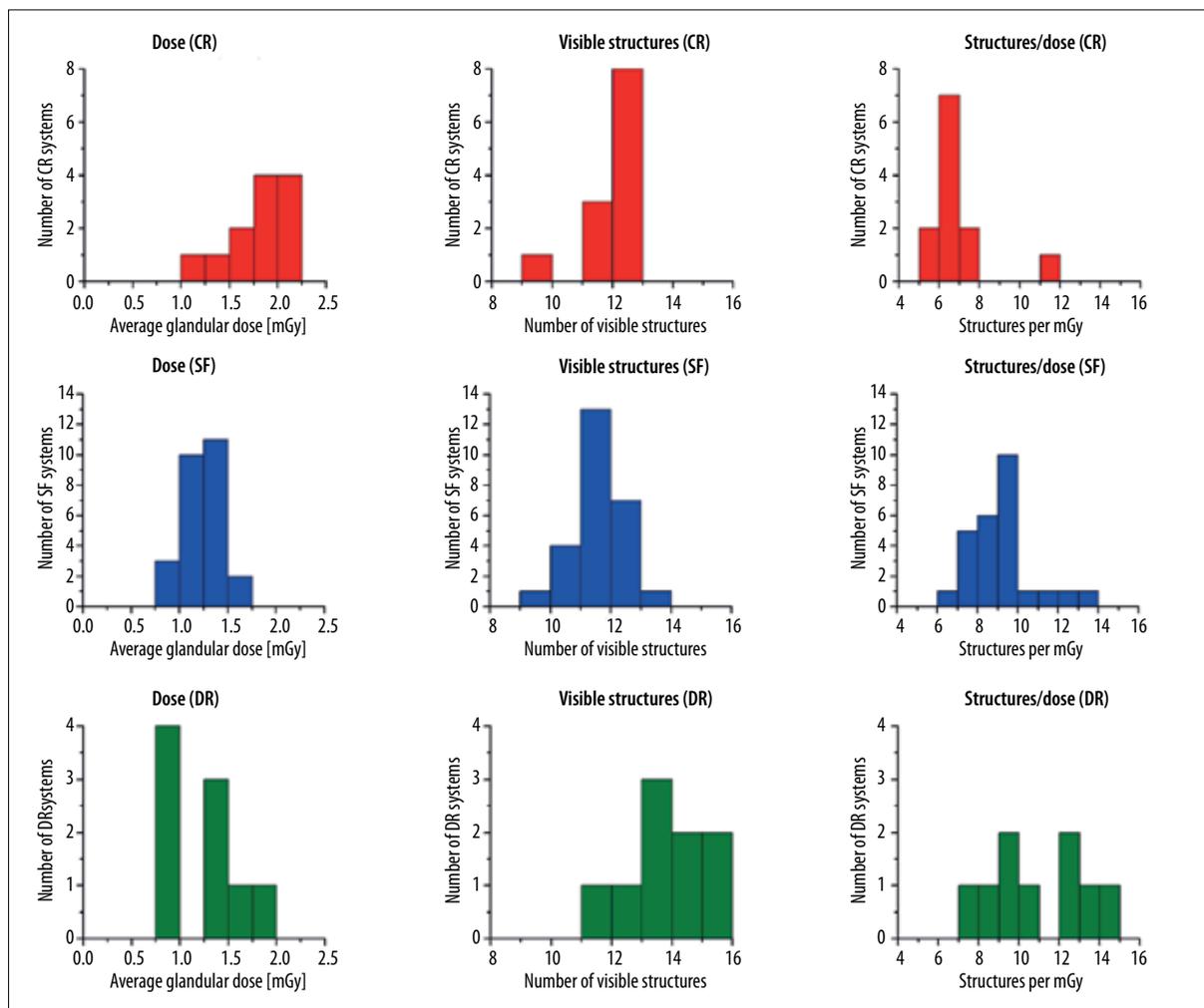


Figure 3. Average glandular dose, number of visible structures in the image of the ACR phantom, and the ratio between the number of visible structures and the average glandular dose for three groups of mammography systems.

SF systems was the presence of artifacts (Figure 4), which decreased the score for the visibility of microcalcifications. The score was decreased for 10 SF systems, and 9 of them did not pass the criteria. The total score for image quality was significantly higher for DR systems than for SF and CR systems, and for CR it was significantly higher than for SF. The difference between CR and SF would be insignificant, if the score for SF systems was not decreased because of artifacts. The ratio between phantom score and the dose was significantly higher for DR than for SF, and significantly higher for SF than for CR systems (Figure 3).

Discussion

The DR systems can provide a low dose and high image quality simultaneously. The SF systems clearly have the potential to provide at least the same image quality as CR systems at a lower dose, but only if they are properly maintained. Observed artifacts could be eliminated e.g. by cleaning or replacement of intensifying screens. It should be noted, that the SF systems evaluated would actually pass tests described in Polish regulations [14]. According to Polish law, a test with an ACR phantom is required only for CR and DR systems, and not for SF systems. Additionally, the

regulations do not mention penalty points for artifacts. The regulations describe the evaluation of artifacts as a separate test, which is required only for digital systems (CR and DR).

Despite a recent update of the requirements, image quality for different types of mammography units is still evaluated in different ways in Poland. It would be desirable to use the same method for all the systems. The ACR phantom could definitely be used for that purpose. The original rules of scoring as outlined by the ACR should be used, including penalty points for artifacts. Penalty points provide valuable information on image quality, especially that they are based on the visibility of artifacts which resemble clinically relevant structures. It may be questioned whether the ACR phantom should be used with weekly frequency as outlined in [14]. Full assessment of image quality with the phantom could be performed less often, given that daily constancy tests are performed for all systems.

In the present study the systems were divided into three categories. This might be an oversimplified division, as each category included systems representing a different level of advancement (e.g. different generations of CR systems). Each of the systems was evaluated in its current state,

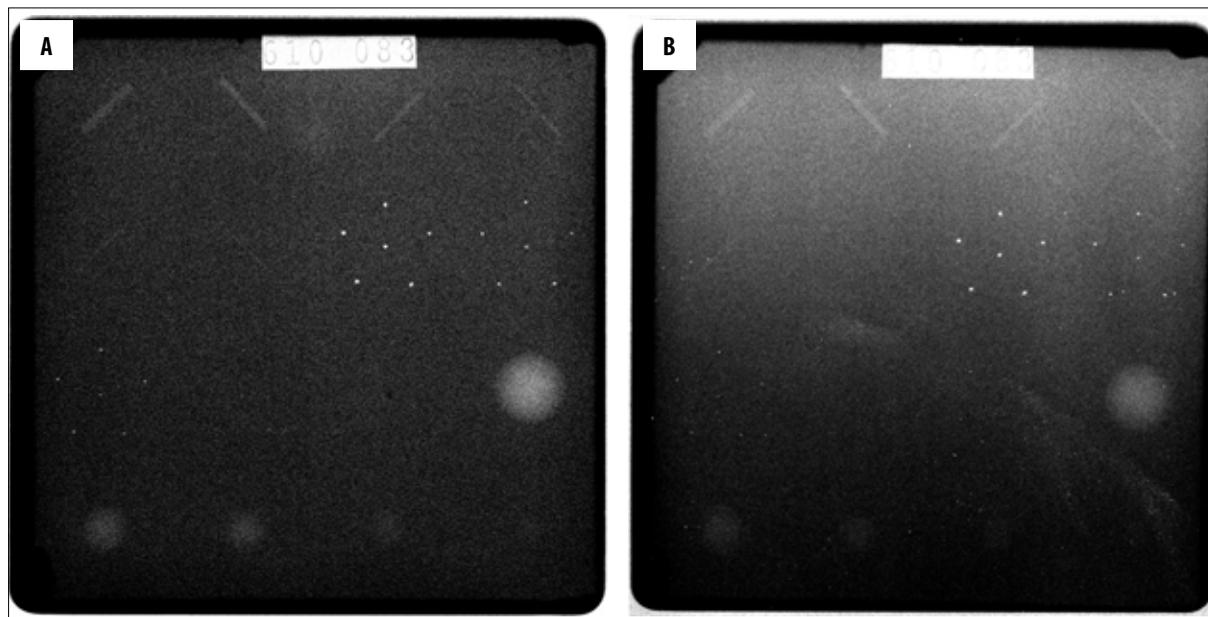


Figure 4. Example images of the ACR phantom. (A) High quality image for modern DR system. (B) Low quality image for a poorly maintained SF system, serious artifacts visible (probably caused by a dirty or damaged intensifying screen).

but the optimization of exposure parameters could be performed for each of them, possibly resulting in dose reduction [20,21]. The measurements were performed only for the phantom simulating one particular type of breast, and no information was obtained on the performance of the systems for breasts of other thickness and tissue composition. Analysis of the individual (patient) doses [22], evaluation of the quality of patient images, or an analysis of epidemiological factors such as the cancer detection rate could be also performed to obtain a complete information. Nonetheless, even this simple assessment has shown that image quality currently offered by evaluated CR mammography systems is not lower than for SF systems, but it is significantly lower than for DR systems, and the doses for the CR systems are significantly higher than for SF and DR systems.

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Conclusions

The best image quality, at a reasonably low dose, was observed for DR systems. The doses for CR systems were significantly higher than for SF and DR systems. The SF systems are capable of delivering the same image quality as CR systems at a significantly lower dose, but they must be properly maintained. Otherwise, the presence of artifacts may seriously degrade the image quality. The ACR phantom could be routinely used to evaluate image quality for all types of mammography systems.

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