SCREEN-FILM *VERSUS* FULL-FIELD DIGITAL MAMMOGRAPHY: RADIATION DOSE AND IMAGE QUALITY IN A LARGE TEACHING HOSPITAL

by

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The objective of this paper is to measure the radiation dose and image quality in conventional screen-film mammography and full-field digital mammography in women referred to mammography examination. Participants underwent bilateral, two-view screen-film mammography or full-field digital mammography. The visibility of anatomical regions and overall clinical image quality was rated by experienced radiologists. Total of 387 women and 1548 mammograms were enrolled in the study. Image quality was assessed in terms of image quality score, whereas patient dose assessment was performed in terms of mean glandular dose. Average mean glandular dose for cranio-caudal projection was 1.5 mGy and 2.1 mGy in full-field digital mammography and screen-film mammography, respectively. For medio-lateral oblique projection, corresponding values were 2.3 and 2.1 mGy. Overall image quality criteria scoring was 0.82 and 0.99 for screen-film and digital systems, respectively. The scores were in the range from 0.11 to 1.0 for different anatomical structures. Overall, full-field digital mammography was superior both in terms of image quality and dose over the screen-film mammography. The results have indicated that phantom dose values can assist in setting the optimisation activities in mammography and for comparison between mammography units. To obtain accurate diagnostic information with an acceptable radiation dose to breast, it is necessary to periodically perform patient dose and image quality surveys in all mammography units.

Key words: mammography, image quality, radiation dose, mean glandular dose

INTRODUCTION

Mammography is a useful imaging technique for early detection of breast cancer. It is modality that requires a high quality image to detect small lesions and to discriminate soft tissues with minimal difference in X-ray attenuation and low physiological contrast [1]. Ionising radiation is an intrinsic part of mammography examination and therefore, each mammography examination must be justified in order to provide a net benefit to the exposed individual [1-5].

Although both analogue screen-film mammography (SFM) and full-field digital mammography (FFDM) are widely accepted for both routine screening and symptomatic breast diagnosis [6], there are concerns related to the optimisation from a radiation protection point of view [7, 8]. The first concern relates to poor image quality that can happen if quality control (QC) is not utilised, while the other concern is the significant variation in patient doses for the same type of examinations [7-9]. While image receptors used in SFM have a limited range of accepted exposures constrained by a limited dynamic range, digital detectors have no such constrains on exposure, and consequently on dose to breast. Digital detectors have a few orders of magnitude wider dynamic range compared to film [10] and there is a possibility that breast doses are significantly higher or lower compared to SFM. This fact also opens a possibility that image quality in digital mammography may be significantly different compared to SFM, due to inherent detector sensitivity of examination protocol selected by a user [11].

The Oslo-I study, comparing screen-film and full-field digital mammography reviled that there is no significant difference in cancer detection rate between these two modalities [12]. Comparison of the FFDM with hard-copy image reading and screen-film mam-

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mography in the UK breast screening programme performed using the meta-analysis indicated that detection rates in FFDM are similar to those in screen-film mammography [13]. Another study also compared the diagnostic accuracy of digital and screen-film screening mammography. The conclusion of this study was that digital mammography may be more effective than screen-film mammography due to better depiction of tumours and micro-calcifications [14]. A recent study [15] comparing both technical and clinical performances of computed radiography (CR) and FFDM brought a conclusion that clinical screening performance parameters are similar in both modalities, whereas the radiation doses employed for CR are generally 60% greater than for FFDM. From the physical-technical point of view, FFDM performs better than CR both in terms of dose and image quality. Similar study compared all three modalities (FFDM, CR, and SFM) in large concurrent cohorts [16]. In terms of cancer detection rate, DR and FFDM presented similar performance while the detection rate in CR was significantly lower. This conclusion raised a need for separate monitoring of CR modality in the screening programmes. Study performed to evaluate technical standards in the screening mammography also challenged the effectiveness of CR mammography as FFDM presented better image quality and lower radiation dose [17].

Thus, transfer from analogue to digital imaging systems requires caution, understanding of digital technologies and specific training of the operators. Although transfer from screen-film to digital system eliminates technical reasons for poor image quality and image rejection, the reasons related to non-technical causes, such as the skills of the operators, remain [10, 18]. To prevent unnecessary exposures, both dose and image quality assessments as essential elements of the optimisation process in SFM and digital mammography, must be monitored.

Image quality in mammography is of utmost importance for early detection of breast cancer. Whereas the dose assessment is rather straightforward, the assessment of image quality is based on the definition of what is considered sufficient diagnostic information for a particular diagnostic task [5, 7]. Image quality is therefore highly dependent on the subjective interpretation of visual data [5, 7, 8]. There is a range of possible image quality evaluation methods such as physical or observer performance (clinical) studies described elsewhere [19]. Among the clinical methods, the receiver operating characteristic method is based on the decision whether the given image contains a pathological structure or not, visual grading analysis (VGA) is based on the comparison of the particular image with a reference image, whereas the image quality criteria scoring (ICS), as a subtype of VGA, is based on absolute scoring using image quality criteria [10, 19, 20].

According to the International Commission on Radiological Protection Publication 103 [21], glandular breast tissue is the most sensitive to radiation. Mean glandular dose (MGD) is a dosimetric quantity related to the risk of carcinogenesis, however it cannot be measured directly and it is calculated from incident air kerma (K_i) and compressed breast thickness (CBT) using appropriate conversion factors both for phantoms and patients [2, 22, 23].

The purpose of this prospective clinical study is to evaluate screen-film and digital mammography in terms of image quality and dose to patients as the first step in the optimisation process following the introduction of digital mammography system into clinical practice.

METHODS

Patients

The study included 387 patients, asymptomatic patients referred to mammography examination. Patients were randomly distributed to the SFM or FFDM units. All women had a mammography examination involving one cranio-caudal (CC) and one mediolateral oblique (MLO) projection in each breast. Magnification, additional projection and images of women with breast implants were excluded from the study.

Mammography units

Study included two mammography units routinely used in a large teaching hospital in Serbia. One unit (Sophie, Planmed Oy, Helsinki, Finland) uses screen-film combination (AGFA Mamoray HDR-C/ Kodak MINR2000) as the image receptor. The unit has built-in post-exposure indication of tube loading and grid in place and uses single target-filter combination (Mo/Mo) for all exposures. The available detector areas were 18 cm 24 cm and 24 cm 30 cm.

Another unit is full field digital (Giotto, IMS, Italy), with a-Se detector technology and 85 μm detector element size. The unit has a single target-filter combination (W/Rh) which was used for all the exposures included in the study. The only available detector area was 18 cm 30 cm.

Dose assessment

Dose assessment was performed for the breasts simulated by standard phantoms of thicknesses ranging from 20 to 70 mm and for patients on both mammography units enrolled in the study. All the exposures were performed in clinical settings using automatic exposure control (AEC), and relevant exposure parameters as tube voltage (kV), target-filter combination, tube loading (mAs), CBT, projection angle and position of the AEC chamber were recorded.

X-ray tube output and half-value layer (HVL) were measured using a calibrated semiconductor dosimeter MPD Barracuda (RTI Electronics, Molndal, Sweden) and high-purity aluminum foils of 0.11-0.18 mm thickness (Goodfellow, Cambridge, UK).

Standard PMMA phantoms of thicknesses ranging from 20 mm to 70 cm PMMA and glandularities ranging from 4 to 97 % [2] were exposed for determination of the MGD at clinical settings and with compression paddle present in the X-ray beam. K_i was obtained by multiplying the tube output in the reference point and the actual tube loading (mAs), and corrected for the actual breast thickness [22]. The reference point is a point 45 mm above the breast support, 60 mm from the chest wall side and laterally centred [2]. The MGD was estimated as a product of K_i and conversion factors for dose assessment with PMMA phantoms [2]. The g- and c-conversion factors used are given as a function of the breast thickness and the HVL of the X-ray beam, while s-factors account for the various target-filter combinations. The g- and c-conversion factors are available both for breasts and the standard breast simulated by PMMA plates. Exposures of PMMA plates of different thicknesses were performed routinely as a part of QC programme to check the performance of AEC system.

Patient dose study included that all women underwent both SFM and FFDM. The examinations were performed by radiographers with adequate experience in mammography imaging. Age, CBT for each projection, tube voltage (kV), target-filter combination, tube loading (mAs) and angle of MLO projections were recorded for each woman. Similarly to the phantom study, K_i was calculated from the X-ray tube output at the tube potential used. The output value was corrected for the CBT and multiplied by the mAs required for each image [2, 22]. Then, MGD for each projection was calculated using age-dependent conversion factors [2,9].

Image quality assessment

The image quality assessment was performed by at least two radiologists experienced in reading mammography images. Image quality assessment was performed for total 278 patients referred to FFDM units and 109 patients referred to SFM unit. As digital and screen-film systems produce obviously different images, the observers were not blinded to the mammography technology. Both sets of images were evaluated as in real clinical situations without restriction regarding time and distance of viewing. Illumination of the viewing rooms was dim, according to the requirements for viewing boxes and medical monitors [24].

Image quality criteria deduced from European Guidelines on Quality Criteria for Diagnostic Radiographic Image [25] were used to guide the radiologists in assessment of the image quality, however the list of criteria was modified to include primarily those significantly contributing to poor image quality (tab. 1). The criteria included those related to the positioning, those related to the exposure parameters, visualisation of important details such as micro-calcifications and masses and overall image quality perception. The radiologists were given an evaluation form for each examination, containing a two-level image grading and a list of possible causes for poor image quality. The image quality scoring was applied in the daily work of radiologists, who made an immediate subjective assessment of image quality, both for the images acceptable for diagnosis and for the rejected ones. Thus, the visibility of anatomical regions, presence of artefact, the exposure quality criteria (contrast, sharpness) and overall subjective perception of image quality, were rated. The image quality criteria are summarised in tab. 1. The visibility of anatomical structures was scored using a simple two-level scale (criteria fulfilled/not fulfilled, a score of 1 was assigned if a crite-

Table 1. Revised version of the European image quality criteria used for image quality assessment in mammography

Image quality criteria	Classification
Visualisation of skin outline	0-not visible/1-visible
Reproduction of vascular structures in the most dense parenchyma	0-not visible/1-visible
Visually sharp reproduction of the pectoral muscle margin in MLO projection	0-not visible/1-visible
Visually sharp reproduction of the cooper ligaments and vascular structures in subcutaneous and pectoral region	0-not visible/1-visible
Adequacy of visualisation and sharpness of micro-calcifications	0-not adequate/1-adequate
Adequacy of contrast in retro-glandular fat tissue	0-not adequate/1-adequate
Adequacy of contrast in glandular tissue	0-not adequate/1-adequate
Visually sharp reproduction of glandular tissue	0-not visible/1-visible
Is background film blackening sufficient?	0-yes/1-no
Is each lesion reproduced on every control image in the same way?	0-yes/1-no
Presence of artefacts	0-yes/1-no
Contrast in glandular tissue, fat tissue, overall contrast	0-not adequate/1-adequate
Overall image sharpness	0-not adequate/1-adequate
Visualisation of micro-calcification	0-not adequate/1-adequate
Visualisation of tumour masses	0-not adequate/1-adequate
Overall image quality	0-not adequate/1-adequate

rion was fulfilled and 0 if it was not). ICS was calculated as a fraction of fulfilled anatomical image quality criteria, based on the summation of all scores, for all observers and all images corresponding to a particular image batch [10, 19, 26]

$$ICS = \frac{\sum_{i=1}^{I}\sum_{c=1}^{C}\sum_{o=1}^{O} F_{i,c,o}}{ICO}$$

where $F_{i,c,o}$ is the fulfilment of criterion c for image i and observer o; I – the number of images, C – the number of criteria, and O – the number of observers. The criteria were applied to the whole examination including two CC and two MLO projections for each patient.

Statistical analysis

Basic features of SFM and FFDM systems were compared using two-tailed Student's t-test for paired samples or Wilcoxon t-test of equivalent pairs at 95% confidence level. A mean score difference with the statistical significance level of p 0.05 was used.

RESULTS

A total of 387 mammographic examinations and 1548 mammograms of CC and MLO projections were considered in this study. All women were imaged using AEC mode, where exposure parameters were selected automatically based on CBT and breast composition. Data on the most important imaging parameters for both mammography units are summarised in tab. 2. Overall, age distribution was similar at the two units. X-ray tube voltage settings were significantly higher in FFDM unit, where tube loading was fairly similar in SFM and FFDM.

Results of MGD assessment are presented in final columns of tab. 2.

The results of image quality assessment are presented in tab. 3. Overall ICS was 0.82 and 0.99 for screen-film and digital systems, respectively. The scores were in the range from 0.11 to 1.0 for different anatomical structures.

Anatomical structures were better visualised in the digital modality when compared with the SFM system, but the difference was not statistically significant as presented in tab. 3. However, digital system was significantly better for the following criteria: presence of artefacts ($p < 0.05$), overall visualisation of micro-calcification ($p < 0.05$), and overall visualisation of masses ($p < 0.05$), as presented in tab. 3 and fig. 1. Subjectively assessed the overall image acceptability was similar in SFM and FFDM.

Figures 2 and 3 show correlation between CBT and MGD for MGD assessed for patients and phantoms. Data was fitted using second-degree polynomial fit. Correlation coefficients (R^2) were 0.297 and 0.857

Table 2. The selected technical and clinical parameters relevant for dose assessment and patient based MGD values at the two mammography units

Unit	Age in years	CBT [mm]		Tube voltage [kV]		Tube loading [mAs]		MGD [mGy]	
		CC	MLO	CC	MLO	CC	MLO	CC	MLO
FFDM	53 1 (42-74)	5.1 0.99 (2.5-7.9)	5.9 1.2 (2.9-9.7)	30 1.5 (25-33)	31 1.6 (26-34)	77 23 (40-196)	101 36 (45-254)	1.5 0.69 (0.54-5.4)	2.3 1.3 (0.13-8.8)
SFM	55 1 (40-65)	4.2 1 (1.5-5.7)	5.5 1.2 (1.7-7.4)	25 1 (23-28)	27 2 (23-30)	91 26 (38-187)	100 35 (48-221)	2.1 0.60 (1.2-4.0)	2.1 0.77 (1.2-5.0)

Table 3. Result of image quality scoring for anatomical structures for digital and screen-film mammography

Characteristics	Digital mammography	Screen-film mammography	Difference of mean score	p
Visualisation of skin outline	1.00	0.64	0.36	<0.05
Reproduction of vascular structures in the most dense parenchyma	1.00	0.97	0.03	0.14
Visually sharp reproduction of the pectoral muscle in MLO projection	1.00	0.99	0.01	0.32
Visually sharp reproduction of the Cooper ligaments and vascular structures in subcutaneous and pectoral region	1.00	1.00	0	–
Adequacy of visualisation and sharpness of micro-calcifications	0.99	0.64	0.35	0.11
Adequacy of contrast in retro-glandular fat tissue	1.00	0.98	0.02	0.16
Adequacy of contrast in glandular tissue	1.00	0.98	0.02	0.16
Visually sharp reproduction of glandular tissue	1.00	0.97	0.03	0.08
Is background film blackening sufficient?	1.00	1.00	0	–
Is each lesion reproduced on every control image in the same way?	1.00	0.72	0.28	<0.05
Presence of artefacts	0.98	0.11	0.87	<0.05

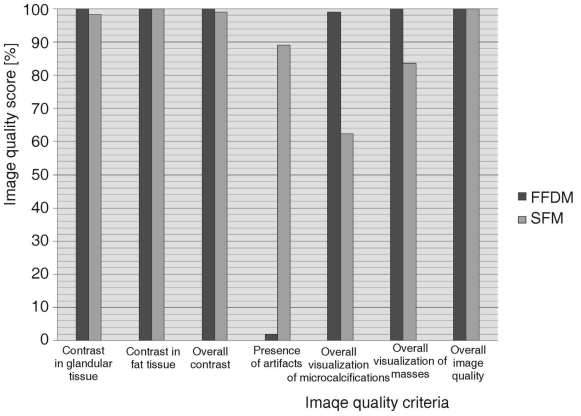

Figure 1. Barr graph presenting results of image quality criteria scoring screen-film and digital mammography system; Score 1: adequate contrast/visualisation/image quality/absence of artefacts, Score 0: inadequate contrast/visualisation/image quality/presence of artefacts

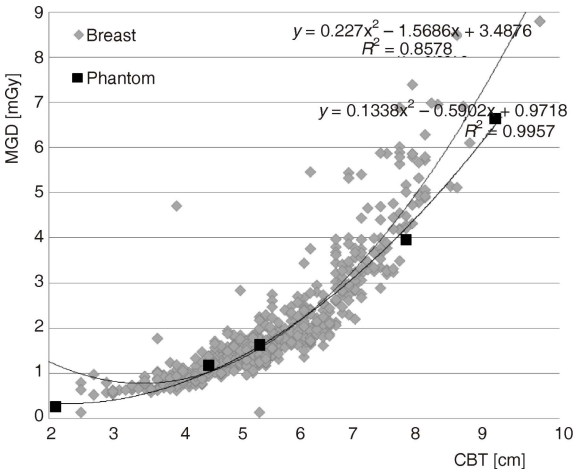

Figure 2. Correlation of mean glandular dose (MGD) and compressed breast thickness (CBT) for patient and phantom dose measurements at FFDM unit

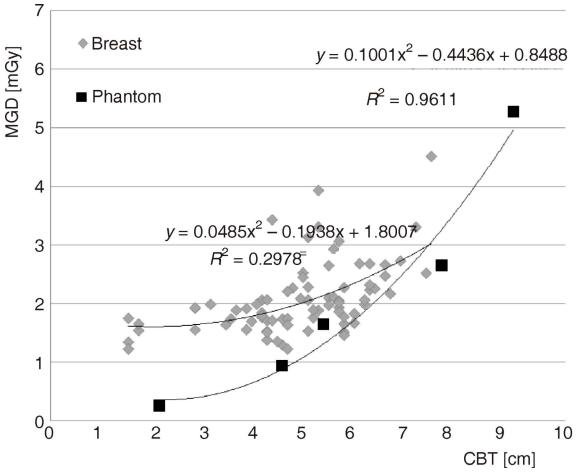

Figure 3. Correlation of mean glandular dose (MGD) and compressed breast thickness (CBT) for patient and phantom dose measurements at SFM unit

for patient-based MGD in SFM and FFDM, respectively. For phantom based MGD, corresponding correlation coefficients were 0.97 and 0.99, respectively.

DISCUSSION

Mean value of assessed MGD is comparable to the results of other similar studies, as presented in tab. 4.Variation between individual patients in two units can be attributed to differences in CBT measurements, compression force or AEC performance in the two units. The reason could partly be in the selection of exposure parameters, but also due to the fact that slow films and screens from different manufacturers are used in SFM. Such a finding urges the need for improving the practice in this particular hospital, primarily by replacing image reception system and introducing regular quality control tests.

MGD was 1.5 mGy and 2.1 mGy for CC projection and 2.3 mGy and 2.1 mGy for MLO projection in FFDM and SFM units, respectively. For some projections, these values are close to diagnostic reference levels of 2.5 mGy [2]. MGD assessed for SFM was higher for CC projection whereas MGD for MLO projection was comparable in FFDM and SFM. This can be explained by exposure parameter selection and beam quality used to generate mammograms. As demonstrated in other studies [9], MGD for MLO projection is higher when compared with CC projection, which could be attributed to the inclusion of the denser pectoral muscle in the image of MLO projection. This trend was observed for FFDM but not for SFM, which indicates that suboptimal images are sometimes used for diagnosis in the later modality.

Although in most cases the MGD was below the acceptable level [2], the range of doses indicated that sometimes very low doses occur, which certainly produce unexposed images and have significant repercussions on image quality. In these cases optimisation would require an increase of patient dose.

In addition to the observed discrepancies between patient and phantom dose, absence of correlation between CBT and MGD and for patients was observed in SFM. In FFDM, phantom dose values for different CBT have generally shown similar trend as dose to patients. The observed difference for the same CBT is a reflection of different compositions (glandularities) of PMMA and real breast and is more pronounced for thicker breasts in FFDM. This is consistent with similar studies [9, 32, 33] and significantly less than the recommended follow-up level of 50%, based on the European protocol for dosimetry in mammography [17]. This finding indicates that phantom dose measurements, which are already a part of quality assurance activities can be used as a test to assess mammography practice in a particular facility and compare doses from different mammography systems.

Table 4. Comparison of MGD values in different studies

Reference	MGD [mGy]			
	Digital		SF	
	CC	MLO	CC	MLO
Tsapaki, *et al.* [27]	–	–	1.2	1.5
O'Leary, *et al*. [28]	1.28	1.37	2.49	2.78
Ciraj-Bjelac, *et al*. [9]	–	–	2.8	4.3
Baldelli, *et al*. [29]	1.27	1.35	–	–
Young, *et al*. [30]	–	–	1.96	2.23
Hauge, *et al*. [31]	1.23	1.35	–	–
Jamal, *et al*. [32]	–	–	1.54	1.82
This work	1.5	2.3	2.1	2.1

Image quality and dose are major performance indicators of mammography practice and an important component of a quality assurance programme. Quantitative assessment of dose is rather straightforward as there are well defined dosimetry protocols [2, 22, 23]. Evaluation of image quality is subjective and associated with uncertainties, in particular if the base on the review of clinical images is produced by a facility [8, 9, 19, 34].

Image quality assessment was used in this study to investigate mammography practice and to compare the image quality between mammography units. The knowledge of the image quality and especially the reasons for poor image quality provided the basis for determination and implementation of corrective actions in line with the causes of poor image quality [7].

In spite of large number of images graded as acceptable in both units, for some parameters there is a significant difference between FFDM and SFM units. The large percentage of images presenting artefact in SFM indicates that images of suboptimal quality are sometimes used for diagnosis, probably due to tolerance of radiologist when applying image quality criteria. Although mammography in MLO projection requires skilled operating staff due to complicated positioning, the evaluation of image quality was better in MLO and was not significantly different than in CC projection. This indicated that causes of poor image quality in SFM were other than breast misplacement and positioning and could be related to problems with image processing, image receptors and an indication of an absent or ineffective QA programme [7, 8].

Several potential benefits of FFDM compared with SFM in mammography screening were reported. Some reports based on phantoms or clinical studies have shown that FFDM is equal or slightly superior to SFM for detection and characterization of mammographic abnormalities, whereas other reports have shown divergent and rather conflicting results [12]. Nevertheless, there is a rapid conversion to digital mammography in breast cancer screening in many countries including Serbia. This study is the first to addresses the transition for SFM to FFDM in Serbia.

The major strength of the study is being prospective and based on real clinical cases. There was no preselection of participants and mammograms were collected in parallel for both SFM and FFDM, while standard, routine methodologies were used for acquisition and viewing of images. Limitation of this study is absence of central reading. Although a full reliable and accurate image quality assessment would include central scoring of images. However, this would probably give only slightly different results, due to subjective judgements, different training levels in scoring images and the tendency to overestimate the quality of images generated by one's self [1, 7]. The results remain however useful as they reflect the actual clinical practice in participating hospital. Besides, employment of image quality scoring is a valuable tool in assessment of mammography practice, as it reduces the degree of subjectivity and draws the observer's attention to image quality elements. Such scoring is a valuable tool for optimisation of radiation protection of patients, it increases awareness of the importance of producing good quality mammograms and, thus, preventing unnecessary patient exposure. This is of particular importance in the preparation phase for of population-based screening programmes in mammography and in transition from SFM to FFDM.

CONCLUSIONS

Results of image quality and dose assessment in two mammography units are presented. FFDM provides some advantages in image quality and dose over the SFM.

Both phantom and patient dose values indicated unnecessary high doses in some cases. The dose in SFM was higher than the dose in the FFDM; therefore, the potential for dose reduction in SFM has to be explored and the practice has to be optimised. To obtain accurate diagnostic information with an acceptable radiation dose to breast, it is necessary to fully implement QA programme in all mammography facilities and to periodically perform patient dose and image quality surveys.

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AUTHOR CONTRIBUTIONS

The study was designed by O. F. Ciraj-Bjelac, T. J. Stantić, and S. S. Stojanović. Clinical image quality assessment was performed by S. S. Stojanović, M. D. Basta-Nikolić, and D. S. Stoiljković. Dose assessment was performed by O. F. Ciraj-Bjelac and D. D. Arandjić. Manuscript preparation was done by T. J. Stantić and O. F. Ciraj-Bjelac. The figures and tables were pre pared by O. F. Ciraj-Bjelac. All authors reviewed the manuscript.

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ПОРЕЂЕЊЕ АНАЛОГНЕ И ДИГИТАЛНЕ МАМОГРАФИЈЕ
Доза за пацијента и квалитет слике у једној великој универзитетској болници

Циљ рада је процена дозе за пацијента и квалитет слике у конвенционалној, аналогној и дигиталној мамографији. Испитаници су били подвргнути билатералном прегледу у две пројекције, а приказивање анатомских детаља и укупан клинички квалитет слике оцењен је од стране искусних посматрача-радиолога. Укупан број испитаника био је 387, а укупан број пројекција 1548. Квалитет слике оцењен је преко параметра ICS (image quality score), а пацијентна доза израчунавањем средње гландуларне дозе. Средња вредност дозе за кранио-каудалну пројекцију била је у случају аналогне и дигиталне мамографије 1.5 mGy и 2.1 mGy, респективно. У случају медио-латерално косе пројекције, одговарајуће вредности дозе биле су 2.3 mGy и 2.1 mGy. Укупан ICS је био 0.99 за аналогну и 0.82 за дигиталну мамографију. Параметар ICS за појединачне анатомске структуре био је у интервалу 0.11-1.0. Показало се да је дигитална мамографија супериорнија у погледу квалитета слике и дозе у односу на аналогну мамографију. Резултати су указали на чињеницу да процена дозе за стандардни фантом може бити од значаја за оптимизацију праксе у мамографији као и за поређење различитих мамографских јединица. За добијање тачне дијагностичке информације уз разумно ниску дозу за пацијента, неопходна је периодична анализа квалитета слике и процене пацијентне дозе у свим мамографским јединицама.

Кључне речи: мамографија, квалитет слике, доза, средња гландуларна доза