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Average glandular doses reported by mammography units: how reliable are they?

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Introduction. Average glandular dose (AGD) values displayed by mammography units are often used to compare doses with diagnostic reference levels, with acceptable and achievable dose levels given with in the European guidelines on breast cancer screening, or between mammography units. The aim of the work was to check the reliability of displayed AGD values by comparing them with independently calculated values.

Material and methods. The comparison was performed for five mammography units, for 20 groups of patients (50 patients each), examined in various periods between the years 2015 and 2020. AGD values were calculated independently for the same patients using the results of measurements.

Results. Observed differences between displayed and calculated doses affected their comparison with acceptable and achievable dose levels.

Conclusions. The displayed AGD values should be used with caution. If reliable information on AGD values is needed, they should be independently calculated using the results of measurements.

Key words: mammography, average glandular dose, DICOM

Introduction

Breast cancer is one of the most common cancers. Mammography is widely used in breast cancer screening and diagnosis [1, 2]. Since mammography uses ionizing radiation, the radiation dose is of radiation dose is an important issue. This is true especially in breast cancer screening, in which examinations are performed largely on asymptomatic women [3, 4]. Diagnostic reference levels (DRLs) should be established and used in all countries belonging to the European Union, and information relating to patient exposure should be included in the report of the medical radiological procedure [5]. In Poland, an internal clinical audit should be carried out every year in each diagnostic radiology facility. During the audit, data on patient exposure should be compared with diagnostic reference levels. The data should be included in the internal clinical audit report, which is submitted to the procedures and audits' committee, and a copy sent to the National Centre for Radiation Protection in Health Care [6].

Radiation dose is expressed in mammography usually as the average glandular dose (AGD) [3, 4, 7]. Acceptable and achievable dose levels in breast cancer screening, as stipulated in the European guidelines on breast cancer screening, are also expressed as average glandular doses [8, 9]. AGD is also used in dose monitoring and optimization [10, 11]. In modern mammography, the average glandular dose is automatically calculated for each exposure and displayed to the operator, as well as stored within a header of a DICOM file. The information may be gathered by dose management systems, allowing

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further analysis [10]. Average glandular doses are calculated by multiplication of air kerma by conversion factors. The conversion factors depend on beam quality, the thickness of the compressed breast, and tissue composition (share of adipose and glandular tissue), and they are based on Monte Carlo calculations. Several different methodologies of AGD calculation are used in various areas of the world [12]. European guidelines on breast cancer screening [8, 9] and the International Atomic Energy Agency (IAEA) recommendations [13] endorse the methodology described by Dance et al. [14, 15].

The aim of the work was to check the reliability of AGD values displayed by mammography units by comparing them with values calculated independently with the Dance method, based on the measurements.

Material and methods

A dose comparison was performed for five full-field digital mammography units of three different manufacturers used in our institute (tab. I). For each unit, data was gathered for several groups of 50 patients (200 exposures), examined in various periods between the years 2015 and 2020 (a total of 20 groups of patients), either for screening or diagnosis. The data included exposure parameters (anode, filter, tube voltage, tube loading), displayed AGD values, compressed breast thickness, and image size (18 x 24 cm^2 or 24 x 30 cm^2). Depending on the period, the data were either noted manually or taken from the headers of DICOM files (e.g. AGD is stored in the DICOM header in the "organ dose" tag, coded [0040,0316]).

Table I. Mammography units used in the comparison

Code	Mammography unit type	Year of installation
A	Siemens Mammomat Inspiration	2010
B	Siemens Mammomat Inspiration	2011
C	Siemens Mammomat Inspiration	2011
D	GE Pristina	2018
E	Hologic Selenia	2007

Several measurements were made in each period, providing the data necessary for an independent calculation of AGD. Air kerma and half-value layer values were measured for all clinically used beam qualities with the Piranha Black 657 meter (RTI Electronics AB, Sweden). Additionally, tests of thickness indicator accuracy were performed according to international guidelines [8, 9, 13], and separately for small and large compression plates. Several 18 × 24 cm slabs of polymethylmethacrylate (PMMA) were used for the test, with thickness ranging from 2 cm to 7 cm. The results of the test were then used to correct data on breast thickness.

Individual average glandular doses were calculated independently for patients, using Dance's method [8, 9, 14–16] and an in-house Excel spreadsheet. Actual exposure parameters, corrected breast thickness data, and the results of tube output measurements were used to calculate incident air kerma. Information on beam quality (anode/filter/HVL) and corrected breast thickness were used to obtain conversion factors. Since the conversion factors are given only for discrete thickness and HVL values, linear interpolation was used.

For each group of patients, displayed and calculated doses were cross-compared, and compared with achievable and acceptable dose levels as outlined in the European guidelines on breast cancer screening [8, 9], including an update published on the website of the European Reference Organisation for Quality Assured Breast Screening and Diagnostic Services (EUREF) in 2017 [16]. The number of cases, where the displayed and calculated doses do not exceed the acceptable and achievable dose levels, was calculated as a percentage of all evaluated cases. Displayed AGD values were compared against dose levels calculated for the displayed breast thickness, while calculated AGD values were compared against dose levels calculated for corrected breast thickness. Since the acceptable and achievable dose levels are given only for discrete thickness values, they were interpolated with a second-degree polynomial.

Table II. Summary of results of dose comparison

Group	Unit	Year/month	Mean AGD [mGy]			% of doses ≤ acceptable level		% of doses ≤ achievable level	
			Calculated values	Displayed values	Mean difference	Calculated values	Displayed values	Calculated values	Displayed values
#1	A	2016/01	1.43	1.39	-0.04	99%	99%	94%	92%
#2	A	2019/03	1.18	1.16	-0.02	100%	100%	100%	100%
#3	B	2015/06	1.30	1.38	0.08	97%	95%	91%	82%
#4	B	2016/07	1.37	1.51	0.13	100%	100%	100%	84%
#5	B	2018/11	1.18	1.17	0.00	100%	100%	97%	97%
#6	B	2019/06	1.05	1.12	0.06	100%	100%	100%	100%
#7	B	2020/07	1.03	1.12	0.09	100%	100%	99%	98%
#8	C	2015/06	1.29	1.32	0.03	98%	97%	95%	92%
#9	C	2016/07	1.31	1.31	0.00	99%	100%	99%	97%
#10	C	2018/11	1.05	1.20	0.14	100%	100%	100%	100%
#11	C	2019/09	1.14	1.27	0.13	100%	100%	100%	97%

Group	Unit	Year/month	Mean AGD [mGy]			% of doses ≤ acceptable level		% of doses ≤ achievable level	
			Calculated values	Displayed values	Mean difference	Calculated values	Displayed values	Calculated values	Displayed values
#12	C	2020/07	1.23	1.37	0.14	100%	100%	100%	98%
#13	D	2018/11	1.72	1.55	–0.17	97%	100%	69%	96%
#14	D	2019/09	1.55	1.39	–0.17	100%	100%	92%	100%
#15	D	2020/07	1.52	1.30	–0.22	99%	100%	93%	100%
#16	E	2015/05	1.96	2.09	0.13	49%	86%	3%	33%
#17	E	2016/07	1.80	2.21	0.41	58%	58%	26%	17%
#18	E	2016/10	1.80	2.05	0.25	67%	73%	36%	46%
#19	E	2018/08	2.13	2.04	-0.09	68%	79%	31%	59%
#20	E	2019/03	2.07	2.10	0.03	66%	81%	34%	48%

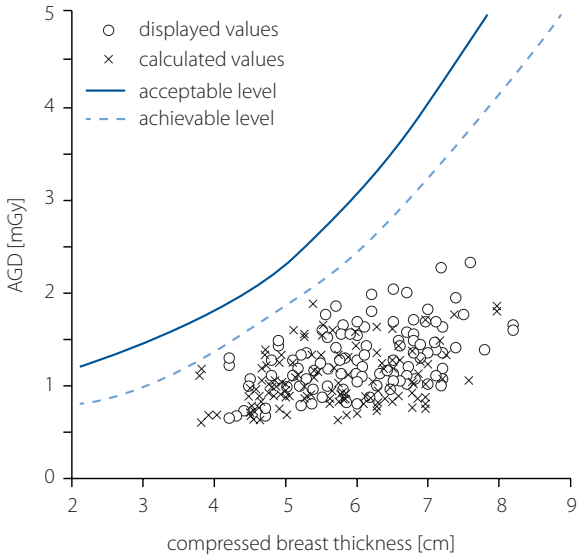

Figure 1. Comparison of displayed and calculated AGD values with acceptable and achievable dose levels for group #10 (Siemens Mammomat Inspiration unit)

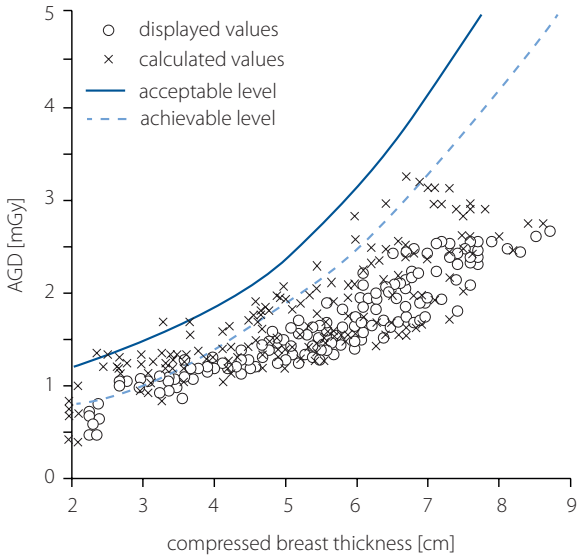

Figure 2. Comparison of displayed and calculated AGD values with acceptable and achievable dose levels for group #13 (GE Senographe Pristina unit)

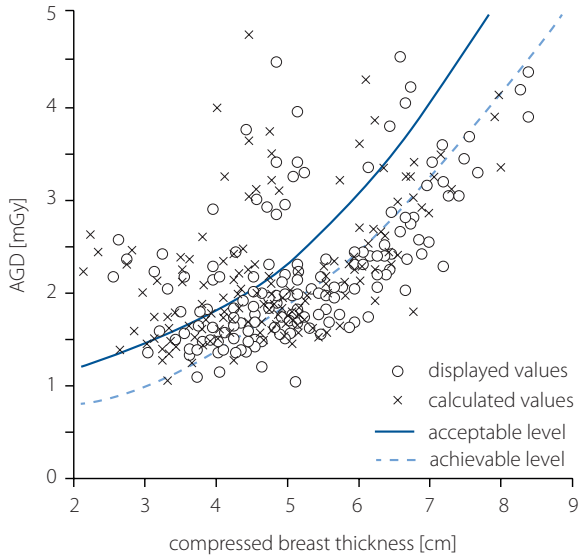

Figure 3. Comparison of displayed and calculated AGD values with acceptable and achievable dose levels for group #20 (Hologic Selenia unit)

Results

The summary of the results is presented in table II. The maximum difference between the displayed and calculated doses in a group of 50 patients was equal to 0.41 mGy (22% of the average dose calculated for that group). Figures 1–3 present a comparison of displayed and calculated doses with achievable and acceptable dose levels for three patient groups examined on three different units. The same scaling was applied on all figures to allow comparisons between them. For data presented in figure 1, the average difference between displayed and calculated doses is relatively large, as it equals 14% of the calculated doses. Despite the differences, all doses (both displayed and calculated) are lower than acceptable and achievable dose levels. For data presented in figure 2, the average dose difference expressed as a percentage of the calculated dose is smaller (9%), but the difference influences the result of the dose assessment. For the displayed values,

achievable dose levels are not exceeded in 96% of cases, but for the calculated values, it is only 69%. For the data presented in figure 3, the average difference of doses is close to zero (1%), but the relatively large inaccuracy of the thickness indicator changes the result of dose evaluation, as the same doses are compared with a lower dose limit (calculated for the corrected breast thickness).

Figure 4 presents a comparison of doses for two groups of patients examined on two different mammography units, separately for the displayed and calculated doses. For the displayed doses, the average and median are lower for the GE unit. The opposite is observed for the calculated doses. Figure 5 presents a comparison of displayed and calculated doses for one patient group, separately for two filtrations (Mo and Rh). The calculated values are mostly within ±5% of the displayed values for one anode/filter combination (Mo/Mo), while for the other one (Mo/Rh), the calculated values are on average 14% lower than the displayed values.

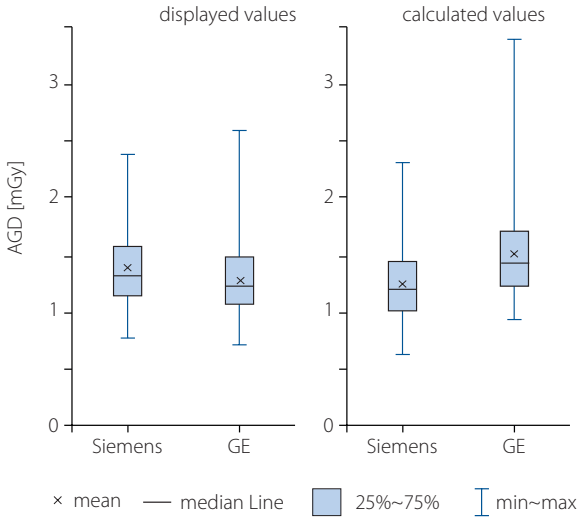

Figure 4. Comparison of displayed and calculated AGD values for two patient groups examined on different units (Siemens Mammomat Inspiration #12 and GE Senographe Pristina #15)

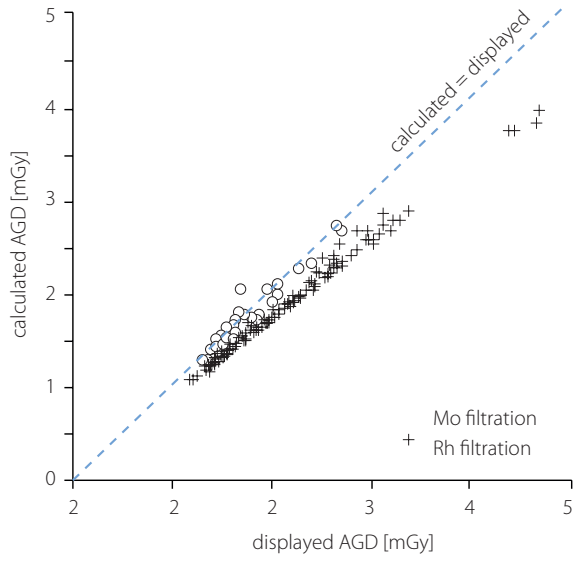

Figure 5. Comparison of displayed and calculated doses for one patient group (#16, Hologic Selenia unit), separately for two filtrations (Mo and Rh)

Discussion

Even a relatively large difference between the calculated and displayed dose values may not influence the comparison of doses with dose limits if the doses are low (fig. 1). On the other hand, a small difference may strongly affect the results of the evaluation if doses are close to the limits (fig. 2). The correction of breast thickness has a twofold effect on dose calculations [17]. Firstly, it has an impact on the calculated distance between the focal spot and beam entrance, thus affecting incident air kerma. Secondly, it has an impact on the conversion factors, which are dependent of breast thickness. Finally, it also has an impact on the effect of dose evaluation, as the dose limits are dependent on thickness (fig. 3). In the European Guidelines, the acceptable difference in thickness indication is ±5 mm [8, 9], while in the IAEA guidelines it is as much as ±8 mm [13]. Different vendors may use different methods for thickness indicator calibration; thus differences of a few mm can be expected. The discrepancies may be different for different beam qualities (fig. 5), and the comparison of displayed AGD values between different units may be misleading (fig. 4).

The differences between displayed and calculated values result from various factors. Aside from the inaccuracy of the thickness indicator, displayed values are determined using tube output data and HVL values stored in the software of mammography units. Since air kerma and half-value layer values may change over time, in this research they were measured independently in each assessed period. Such measurements are repeated in our institute every year and after each major service maintenance (e.g. tube replacement, detector replacement, detector calibration performed by service) to keep the calculated values reliable.

Calculated values also have limited accuracy. Measurement uncertainty of calculated AGD values may be as large as 14–20% [18, 19]. However, all the measurements and calculations presented in the current work were at least performed with the same methods and equipment. Testing thickness indicator accuracy with rectangular PMMA may not be equivalent to the clinical situation, but it was performed in the same way for all units. The same radiation detector, the same formulas, and conversion coefficients were used in all calculations. That said, methods used by different vendors to determine displayed AGD values are not described in detail. Additionally, while to our knowledge Dance's method was used by all vendors in our study, several other methods exist [12]. Another breast dosimetry method is under development by one group, which is simultaneously an American Association of Physicists in Medicine task group (AAPM TG282) and a working group of

the European Federation of Organisations for Medical Physics (EFOMP). Ultimately, this may result in the standardization of methods, but during the transitional period there will be even more methods in use.

In the case of screening examinations, patient groups consist of asymptomatic women. Breasts have typical structure, and the dose generally raises with breast thickness (e.g. fig. 1). In diagnostic examinations, lesions of various types may be presented in the breast [20]. Patient groups are less uniform, which may explain the presence of outliers in dose distribution (fig. 3). Relatively small groups of patients which were used in the work were enough to compare displayed and calculated doses and to prove that the effects of such comparison will be different for different mammography units. The presented results may not fully represent the distribution of doses for all women examined with a given mammography unit. Larger datasets maybe needed for evaluation of patient doses, for dose optimization, or to establish reference dose levels. In general, AGD values could be independently calculated for each exposure, based on the measured HVL and air kerma values, and using corrections of thickness readings. This would make it possible to include reliable information on patient exposure in the report of the medical radiological procedure.

Other researchers reported similarly: for a given method, differences between the displayed and calculated dose for a standard breast may reach 18% [12]. The situation may be similar in other X-ray imaging modalities. Documents published by the European Commission allow for relatively high uncertainty for DAP/KAP (dose/kerma-area product) meters, which provide patient exposure information in radiography and fluoroscopy (acceptability limit is ±25% for radiography, ±35% for fluoroscopy) [21]. It is also known that the energy response of a DAP/KAP meter may vary by 20% between the different beam qualities (different kVp and filtration settings) [22]. In computed tomography, it is expected that there will be agreement between measured and displayed computed tomography dose index (CTDI) within ±20% [21]. Discrepancies higher than 20% are occasionally observed, especially for low kV values [23]. Besides, the definition of CTDI has changed over time, and different CT models may use different definitions [24]. Recently, the size-specific dose estimate (SSDE) is gaining popularity in CT. While it is not yet routinely reported by CT scanners, it may be calculated by dose management systems. However, various methods may be used for it, which leads to different results [25]. The differences may affect comparisons of dose quantities with DRLs and between units in a similar way as in mammography.

Conclusions

The observed differences between displayed and calculated doses can affect the results of comparison of doses with acceptable and achievable dose levels, DRLs, or comparisons between different units in various ways, depending on dose levels and the type of mammography unit. If reliable information on average glandular dose is needed, e.g. for quality audit purposes, the values should be independently calculated using current results of measurements. The displayed values should be used with caution, and the uncertainty of displayed doses and compressed breast thickness should be taken into account.

Conflict of interest: none declared

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