Original papers • Artykuły oryginalne

On the possibility of reducing doses received by patients during mammography screening

Jerzy Tołwiński, Ewa Fabiszewska, Barbara Gwiazdowska, Wojciech Bulski

P u r p o s e. The aim of the study was to collect and to evaluate a set of data of a large group of patients examined with different mammography units, and to compare the individual doses (D_i) with the standard average glandular dose (standard AGD) established for a particular mammography unit. The comparison was intended to allow to formulate recommendations of procedures in order to limit the exposure of patients, procedures which are beyond the scope of routine testing of mammography facilities.

M a t e r i a l a n d m e t h o d s. The presented analysis bases on the results of the measurements of the standard AGD, taken from 82 protocols of quality control of mammography equipment; – 16 histograms of dose distribution for individual patients (D_i) examined with 16 different mammography units; – 2 histograms for patients examined with one mammography unit by the radiographer before and after training; – histograms of individual doses (D_i), corresponding high-voltage (kV) and tube-loading (mAs) values, for one mammography unit (Elscint-Glory 2001) which was equipped with an automatic optimisation of contrast (AOC) system. The measurements were carried out according to the procedures of the American College of Radiology (ACR). Basing upon the constructed histograms we performed a comparison of the standard AGD values with the individual doses (D_i).

R e s u l t s. The frequency distribution of the standard AGDs (Figure 1) shows a considerable dispersion of values, ranging between 0.5 and 2.5 mGy. The histograms of the individual glandular doses (D_i) calculated for individual patients, examined with different units (Figure 2) suggest that the choice of high voltage made by the radiographers may be incorrect i.e. the high voltage was not increased sufficiently with the increase of breast thickness. The incorrect value of the high voltage (low value) may be also set up by the AOC system (Figure 4). Two histograms for patients examined with one mammography unit by the radiographer before and after training (Figure 3) indicate the possibility of decreasing the individual doses by proper selection of the high voltage value. The parameters, resulting from the histograms of the D_i values (mode, median, mean), shown in Figures 2, 3 and 4 are summarized and compared with the standard AGD calculated for the same unit (Table I). The results show that the acceptance of a single parameter for evaluation of doses received by patients during mammography examinations is insufficient.

C o n c l u s i o n s. The assessment of the standard AGD is insufficient for the evaluation of the procedures of mammography screening. The histograms of individual dose distribution should be used for controlling of the conditions of these examinations.

O możliwości obniżenia dawek otrzymywanych przez pacjentki podczas mammograficznych badań przesiewowych

C e l. Celem pracy było zebranie i ocena danych dotyczących dużej liczby pacjentek badanych różnymi mammografami i porównanie indywidualnych dawek D_i ze standardową średnią dawką gruczołową (standardową AGD), określoną dla poszczególnego mammografu. Porównanie to zmierzało do zarekomendowania procedur wykraczających poza rutynowe testy kontroli mammografów, a umożliwiających ograniczenie ekspozycji pacjentek.

M a t e r i a ł i m e t o d y. Zaprezentowana analiza oparta jest na: – wynikach pomiarów standardowej AGD zaczerpniętych z 82 protokołów kontroli jakości wyposażenia mammograficznego; – 16 histogramach rozkładu dawki indywidualnych pacjentek (D_i), badanych różnymi mammografami; – 2 histogramach, dla pacjentek badanych tym samym mammografem przez technika przed i po przeprowadzonym szkoleniu; – histogramach dawek indywidualnych i odpowiadającym im histogramom wysokiego napięcia (kV) i obciążenia lampy (mAs), pomierzonych mammografem Elscint-Glory 2001, który był wyposażony w system automatycznej optymalizacji kontrastu (AOC system). Pomiary prowadzono zgodnie z procedurami

Medical Physics Department
Maria Skłodowska-Curie Memorial Cancer Center
and Institute of Oncology, Warsaw, Poland

stosowanymi przez The American College of Radiology (ACR). Na podstawie skonstruowanych histogramów przeprowadzono porównanie wartości standardowych AGD z wartościami dawek indywidualnych.

Wyniki. Rozkład częstości wartości standardowych AGD (Ryc. 1) pokazuje znaczny rozrzut tych wartości, od 0,5 do 2,5 mGy. Histogramy indywidualnych dawek gruczołowych D_i obliczonych dla indywidualnych pacjentek, badanych różnymi mammografami (Ryc. 2), sugerują nieprawidłowy wybór wysokiego napięcia, tzn. wartość wysokiego napięcia nie była dostatecznie podnoszona prze technika przy wzroście grubości piersi. Nieprawidłowa wartość wysokiego napięcia (za niskie) może być również wybierana przez system AOC (Ryc. 4). Dwa histogramy, dla pacjentek badanych tym samym mamografem, ale przez technika przed i po szkoleniu (Ryc. 3) wskazują na możliwość obniżenia dawki indywidualnej przez właściwą selekcję wartości wysokiego napięcia. Parametry wynikające z histogramów wartości D_i (moda, mediana, średnia), pokazane na Ryc. 2, 3 i 4, zostały zestawione i porównane z wartościami standardowej AGD, obliczonymi dla tego samego mammografu (Tab. I). Pokazane wyniki wskazują, że przyjęcie jednego parametru dla oceny dawek otrzymywanych przez pacjentki podczas badań mammograficznych, jest niewystarczające.

Wnioski. Oszacowanie wartości standardowej AGD jest niewystarczające przy ocenie procedur mammograficznych badań przesiewowych. W celu kontroli warunków przeprowadzania tych badań należy stosować histogramy dawek indywidualnych.

Kay words: quality control in mammography, dosimetry, doses in mammography, mammography screening
Słowa kluczowe: kontrola jakości w mammografii, dozymetria, dawki w mammografii, mammograficzne badania przesiewowe

Introduction

The basic aim of mammography as a diagnostic tool, especially mammography screening, is the early detection of micro neoplasmic lesions in the breast. Nevertheless, with mammography, there always exists the risk of radiation-induced carcinogenesis whenever the patient exposure is repeated several times, as may be the case in the mammography screening programme. For a screening programme to be justified in terms of radiation protection, the benefit of breast screening must be greater than the risks of inducing cancer by the use of ionising radiation. Also, the screening should be performed only with high quality units and following procedure guidlines ensuring good image quality with the smallest possible doses absorbed by the patients [1].

There is no unified recommendation as to the value of a "permissible" dose received by the patient, as well as to the methods of establishing these doses.

In the case of patients undergoing mammography the evaluation of the exposure to ionising radiation bases on the assessment of the standard average glandular dose – the so-called standard AGD. The AGD is also called the mean glandular dose – MGD [2].

The standard AGD, which is a physical parameter, is generally calculated under certain assumptions, concerning mainly tissue composition and compression of the breast (50% glandularity, compression 4-5 cm, depending on the protocol used), from dose quantities determined at the position of the entrance surface of the breast. In this context, entrance surface air kerma (ESAK) free in air (i.e. without backscatter) has become frequently used quantity. The AGD is derived from measurements of the ESAK and of the half value layer (HVL), making use of tabulated conversion factors from ESAK to AGD. The conversion factors, based on the Monte Carlo calculations and verified experimentally differ – as they have been established by various authors. To represent the exposure to radiation, the standard AGD value should be representative to the largest group of women among the entire female population fulfilling the age criteria for these examinations.

In relation to mammography screening, there exist different national protocols which, to a varying extent, deal with the evaluation of the absorbed dose as a part of quality assurance. For countries where national guidance and protocols are not yet available, "The European Protocol on Dosimetry in Mammography" provides consistent methods of dose measurement and assessment [3]. According to this protocol the analysis of the risk–benefit ratio is far from easy to establish, but at least "Average AGD per examination and per exposure has to be used as risk assessment". The assessment of the average AGD is based on recording the exposure conditions and the thickness of the compressed breast based on a sample of at least 50 patients. If the Average AGD per exposure (i.e. D_i in the notation of this paper), differs by more than +/-50% from the standard AGD, the cause of such discrepancy must be investigated.

The "European guidelines for quality assurance in mammography screening" contain an appendix "European Protocol for the quality control of the technical aspects of mammography screening" [4]. This protocol does not include detailed information on the determination of the dose to the breast, but it specifies two values of ESAK: ESAK acceptable of less than 15 mGy and ESAK desirable of less than 14 mGy. From the values of ESAK the AGD can be calculated for specific measuring conditions. As stated in [4], the AGD is typically less than 2.0 mGy.

According to the "Mammography Quality Control Manual" of the American College of Radiology (ACR), the value of AGD (understood as standard AGD) must not exceed 3 mGy per view for screen-film image receptors. If the value exceeds this level, action must be taken to evaluate and eliminate the cause of excessive dose [5].

For the results and conclusions drawn from this work, the issue on which of the protocols would be adopted for dose measurements was not significant. As the work was started as early as in 1992 and some measurements were performed in cooperation with the ACR, its protocols were used. (ACR approved for accreditation the GE Seno 6006T 1992 – unit and the mammographic imaging service of the Maria Skłodowska-Curie Memorial Cancer Center in Warsaw from 30.08.1995 through 30.08.1998)

No matter what protocol is used, the standard AGD value is a physical parameter – one value for a "standard breast" examined with given mammography equipment, and does not represent the dose received by an individual patient. It was expected that the individual differences in breast anatomy and the resulting selection of different exposition parameters set by the radiographers might have been the source of differences between the standard AGD and the individual dose D_i.

The aim of the present work was to collect and to evaluate a set of data concerning a large number of patients examined with different mammography units and to compare the individual doses D_i with the standard AGD established for a particular unit. The comparison was aimed at allowing to form the recommendations of procedures to limit the exposure of patients, procedures which are beyond the scope of routine testing of mammography facilities.

Material and methods

The presented analysis is based on:
- The results of the measurements of the standard AGD, taken from 82 protocols of quality control of mammography equipment, carried out during the 1997-2002 time-frame, for a number of mammography units in various cities in Poland. The standard AGD is one of the parameters of the ACR-quality control protocol.
- 16 histograms of the dose distribution for individual patients – D_i, examined with 16 different mammography units; the number of expositions for each histogram was approx. 100; in
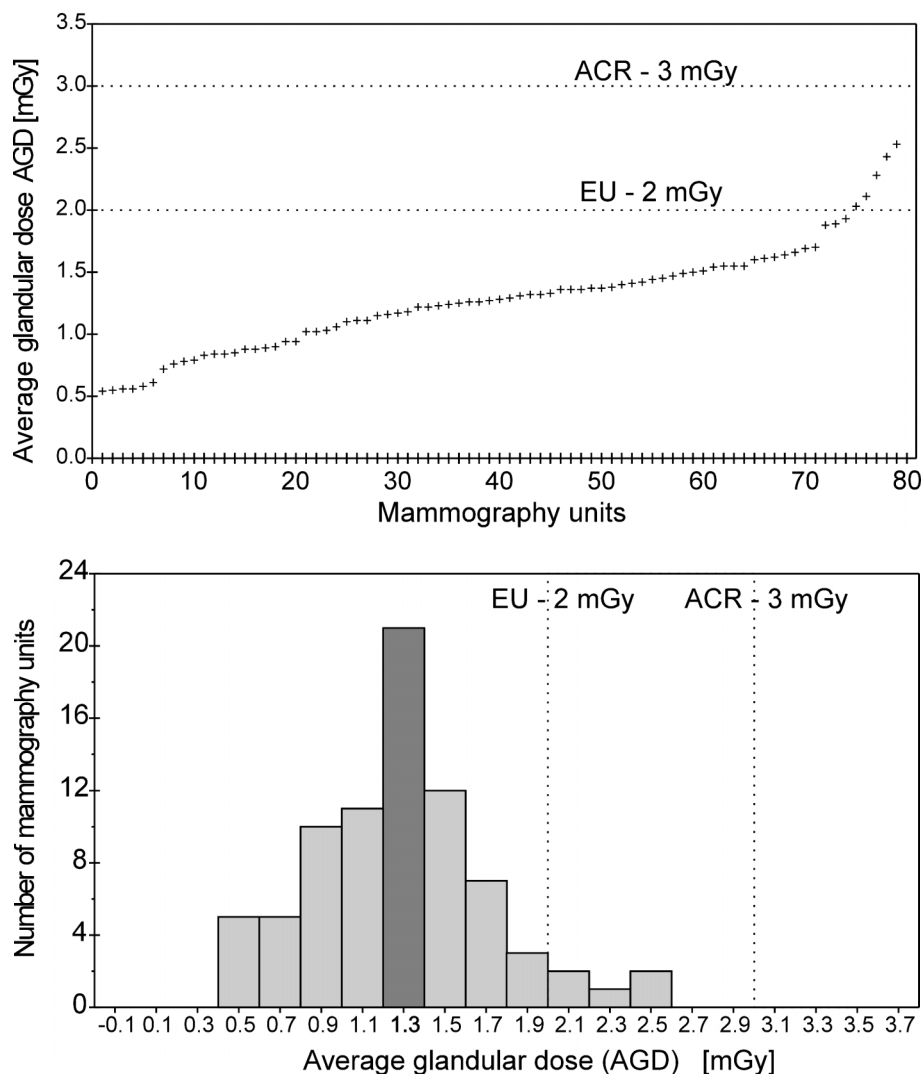
Figure 1. Frequency distribution and the histogram of the standard AGDs measured according to the ACR procedure in various mammography facilities. On the plot the values: 3 mGy (according to ACR) and 2 mGy (according to the EU protocol) are marked. The most frequent standard AGD value on the histogram is 1.3 mGy

each case, the high voltage values were set up by radiographers according to their experience.

- 2 histograms for patients examined with one mammography unit (GE 600 T). In case of the first histogram the high voltage values were set-up by the radiographer according to his experience. In case of the second histogram, the radiographer was trained and the tube voltage was set up to such a value for which the dose should not exceed 3 mGy, without loss of image quality – according to proposals described by Fabiszewska et al. [6, 7].

- The histograms of individual doses D_i, corresponding high-voltage (kV) and tube-loading (mAs) values, for one mammography unit (Elscint – Glory 2001), which was equipped with the AOC (automatic optimisation of contrast) system. The AOC system chooses a possible low value of the high voltage, permitting the achievement of good image contrast (i.e. good image quality), but not exceeding the value of mAs, permissible for the given X-ray tube.

The measurements were carried out according to the ACR – procedures. ESAK was measured with an ionisation chamber calibrated for the energy range 20-35 kV. Image quality evaluation was done with the RMI-156 phantom designated for ACR – accreditation programme. In each case, before the measurements, the background of the phantom was adjusted to 1.4 OD (excluding base and fog) using an automatic exposure control system (AEC system). The individual doses D_i were established on the basis of the exposition parameters, and the thickness of the compressed breast was recorded by the radiographer. The calculation procedure of D_i was identical to the one used for the calculation of the standard AGD.

On the basis of constructed histograms, comparison of AGD values with the individual doses D_i was performed.

Results

In Figure 1, the frequency distribution of the standard AGDs is plotted. Alongside, a histogram of dose dispersion is presented. Two values: 3 mGy (according
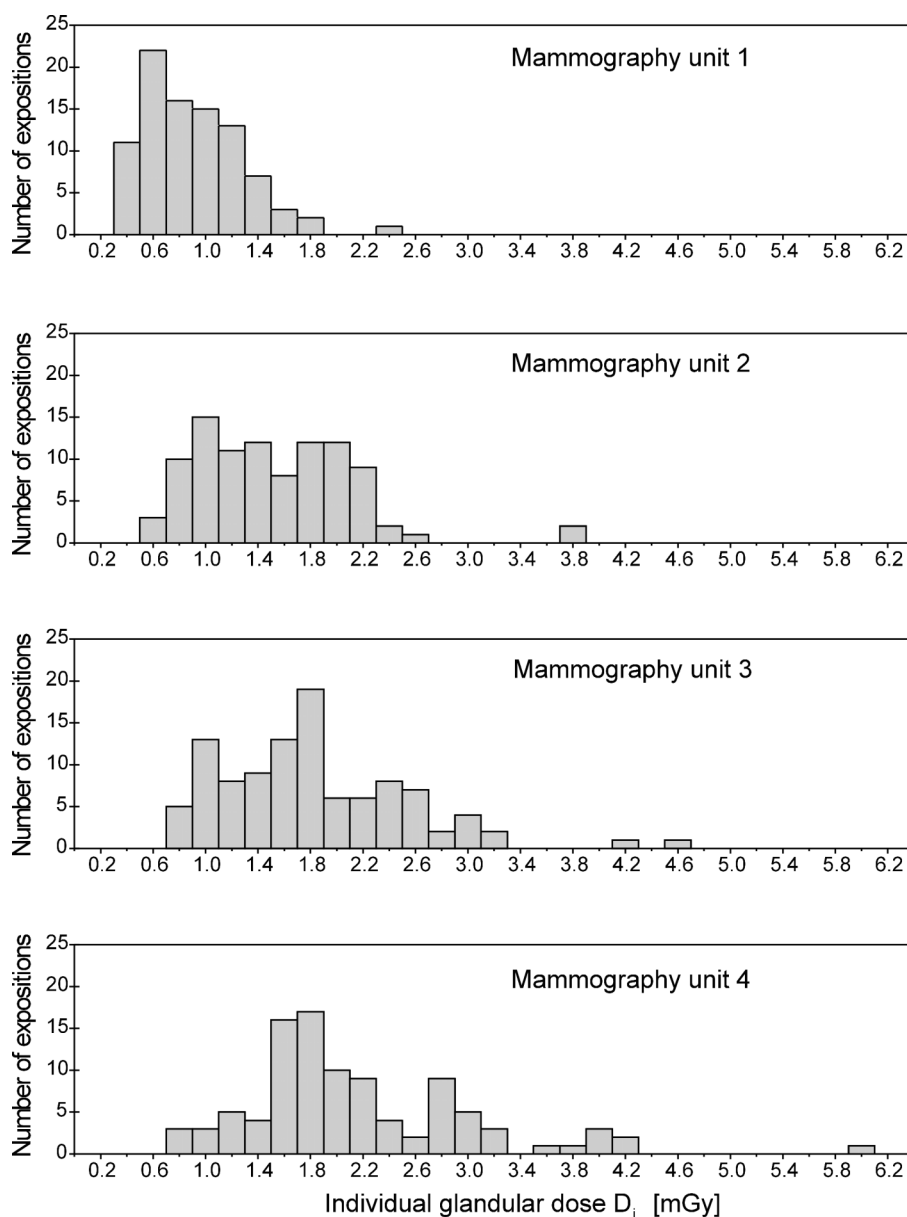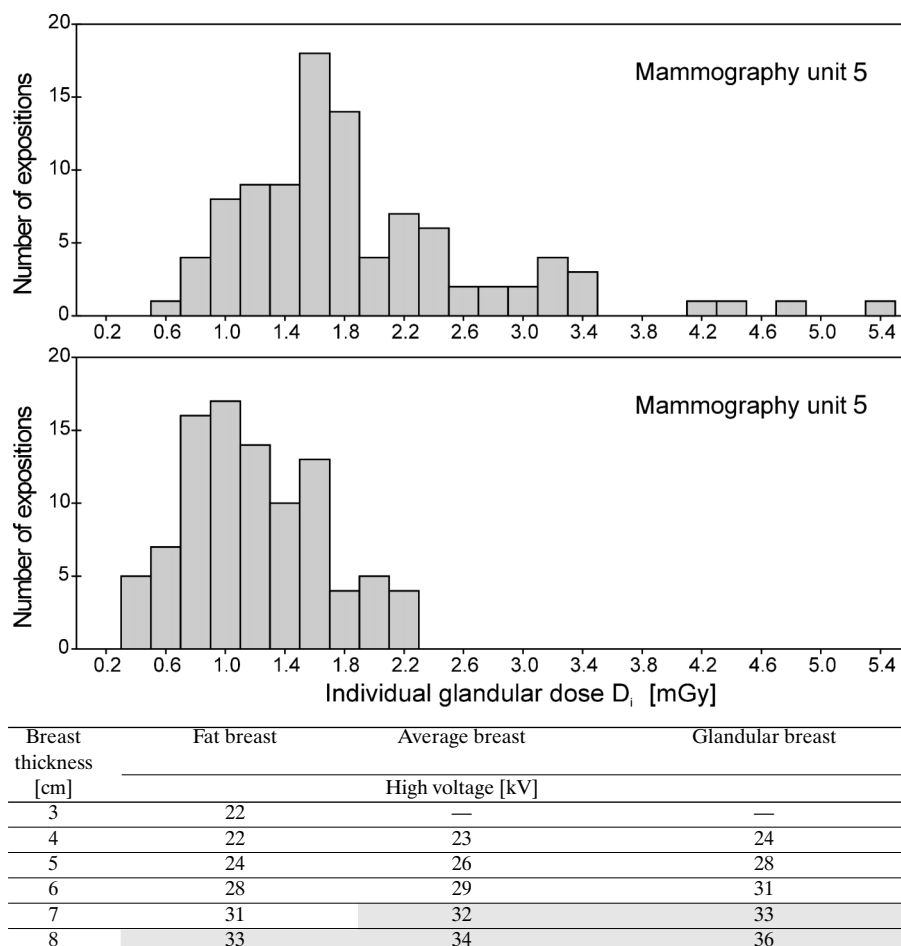

Figure 2. The histograms of individual doses (D_i) calculated for individual patients, examined with different units. Each histogram is based on approx. 100 expositions. The values of standard AGDs were: 0.8, 0.7, 0.9, 0.9 mGy, respectively for units 1, 2, 3, 4

to the ACR) and 2 mGy (as those mentioned in the European Guidelines) are marked on the plot and on the histogram. As can be seen on the histogram, the most frequent standard AGD value was 1.3 mGy. All values were below 3 mGy, and only a few of them exceeded the value of 2 mGy. Considerable dispersion of the standard AGD values, ranging between 0.5 and 2.5 mGy, may be explained by the large variability of the sensitivity of the detectors used (films and intensifying screens) during the 1997-2002 period in various hospitals. According to the data in the quality control protocols, the image quality was satisfactory in all cases.

Four examples of the histograms of the individual glandular doses D_i calculated for individual patients, examined with different units, are presented in Figure 2. The histograms were selected out of sixteen in such a way that they represent the best (unit 1), the worst (unit 4), and two "intermediate" distributions (units 2 and 3). The standard AGD values were: 0.8; 0.7; 0.9; 0.9 mGy, respectively, for units 1, 2, 3, and 4, showing that they

did not apply to the largest group of women among the examined population. Almost all histograms are shifted to the higher values of doses, as compared to the standard AGD values. It could be suspected that the shift is due to the different anatomy (thicker breast) of examined Polish women, as compared to the standard breast. However, the non-regular shape of the histogram, its rather positive skew, and many cases of doses above 2 mGy suggest that the choice of high voltage made by the radiographers may be incorrect i.e. the high voltage was not sufficiently increased with the increasing breast thickness. The low value of high voltage led to the increase of the current-time product, because automatic exposure control systems maintain the necessary optical density of the film, thus ensuring high image quality. This resulted in a significant increase of the dose D_i in a considerable number of patients (especially those with thicker breasts).

Therefore, in the case of one mammography unit (GE 600 T – unit 5 in the Table I) two histograms, for about 100 exposures each, were built (see Figure 3). In

Breast thickness [cm]	Fat breast	Average breast	Glandular breast
		High voltage [kV]	
3	22	—	—
4	22	23	24
5	24	26	28
6	28	29	31
7	31	32	33
8	33	34	36

Figure 3.
a) Two histograms of individual doses (D_i) for approx. 100 exposures performed with a General Electric 600T mammography unit. In the case of the first histogram, the high voltage values were set up by the radiographers according to their knowledge and experience, in the case of the second histogram they were set up according to the parameters of the examined breast
b) The table for radiographers which helps to choose high voltage depending on the thickness of the breast and its granularity. The table was constructed with the assumption that the dose per exposure should be less than 3 mGy. For the conditions in the shaded area, D_i exceeds 3 mGy but the acceptable image quality is achieved
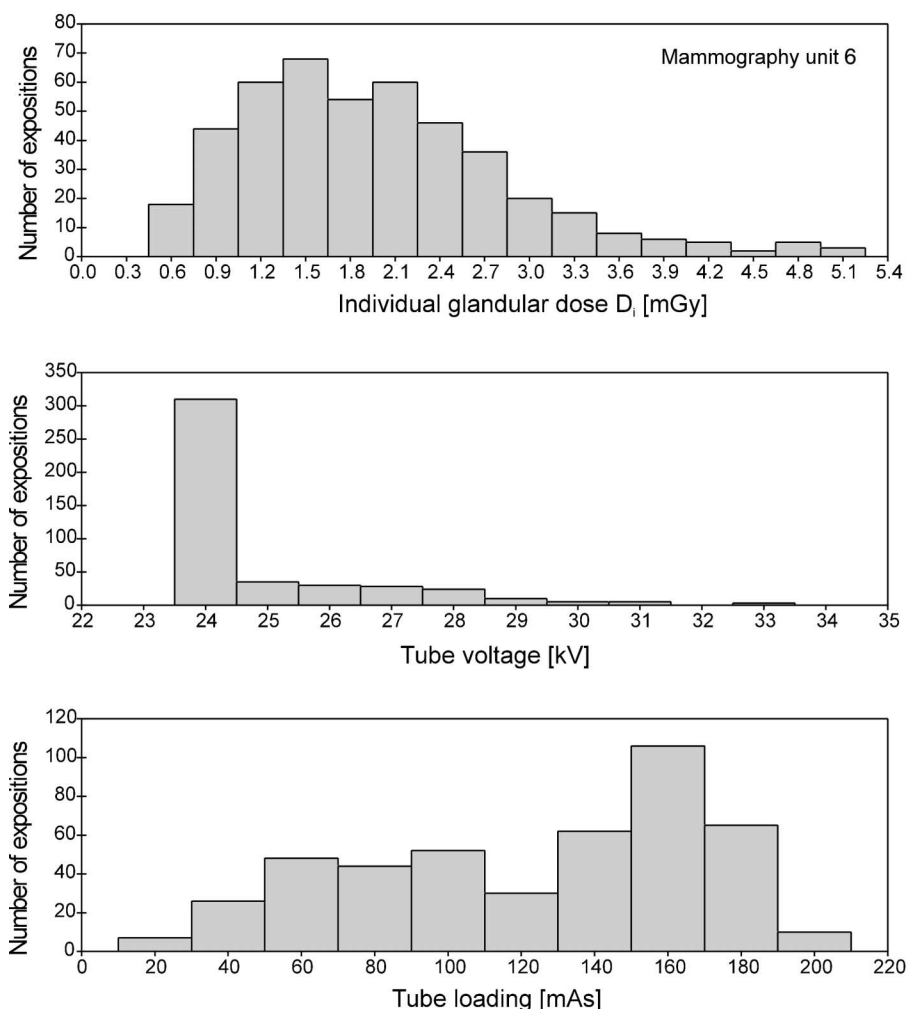
Figure 4. The histograms of individual doses (D_i), corresponding high voltage (kV), and tube loading (mAs) values for a group of patients (450 expositions) examined with the Glory-Elscint mammography unit equipped with an automatic optimisation of contrast (AOC) system

the case of the first histogram the high voltage values were set up by the radiographer according to her experience without any suggestions. There are some very high doses observed on this histogram. In the case of the second histogram the radiographer was properly trained and the tube voltage was set according to the data in the table (below the histograms), constructed by Fabiszewska et al. [6, 7]. High voltage value that should be applied may be found on the crossing of the row with appropriate thickness of the compressed breast and the column with appropriate tissue composition. (The examination under the conditions given in the shaded area causes D_i to exceed the value of 3 mGy, however, acceptable image quality is achieved). The difference between the histograms indicates the possibility of lowering the individual doses by proper selection of the high voltage value, while at the same time retaining image quality.

In Figure 4 we present the histograms illustrating the distribution of individual doses D_i and corresponding high voltage (kV) and tube loading (mAs values) for the Elscint-Glory mammography unit (unit 6 in Table I) equipped with an AOC system. It may be seen from the histogram of the high voltage values, that the AOC system

selected high voltage value of 24 kV for over 70% expositions. The low value of high voltage led to the increase of the current-time product, and resulted in the increase of the dose D_i in case of a considerable number of patients.

In Table I, the parameters, resulting from the histograms of the D_i values (mode, median, mean), shown in Figures 2, 3 and 4 are summarized and compared with the standard AGD calculated for the same unit. Only in the case of the histogram, built from the "settings" of the trained radiographers (unit 5) and those for units equipped with the AOC system (unit 6), the differences between the standard AGD and the mode of the D_i distribution can be considered satisfactory (=10%). The values of median and mean confirm that the histograms are positively skewed (except for unit 1 and 5). In some cases the mean individual dose $\bar{D}_i$ is over twice as high as the standard AGD. According to [3] the AGD should not be exceeded by more than 50%. In the last column, the percentage of doses above 2 mGy is shown. According to [3], the presented units and/or radiographers are not fit for performing the screening, except for unit 1 and 5 (the same unit but with a properly trained radiographer). The

Table I. Parameters resulting from the histograms of D_i as compared to the standard AGD

Mammography units	Standard AGD	Individual dose histogram	Individual dose histogram	Individual dose histogram	Number of expositions above 2 mGy
		MODE	MEDIAN	MEAN	
	mGy	mGy	mGy	mGy	%
Unit Nr 1 Philips MD-UC	0.8	0.6	0.8	0.9	1
Unit Nr 2 Lorad M.-III	0.7	1.0	1.4	1.5	15
Unit Nr 3 Metaltr. Venus	0.9	1.8	1.6	1.8	31
Unit Nr 4 GE 600T	0.9	1.8	1.9	2.2	36
Unit Nr 5 GE 600T	1.0	1.6	1.6	1.9	32
Unit Nr 5 GE 600T	1.0	1.1	1.1	1.2	4
Unit Nr 6 Elscint-Glory	1.4	1.5	1.7	2.0	46

example of unit 6, for which the standard AGD and mode is almost the same, but the percentage of the doses above 2 mGy is the greatest in the presented material, indicates that the acceptance of a single parameter for estimation of doses received by patients is insufficient for such irregular histograms as obtained from clinical mammography examinations.

Conclusions

1. Justification of exposure of patients is a fundamental principle of mammography screening.
2. The assessment of the standard AGD is not sufficient to evaluate the procedure of screening.
3. The histograms of individual dose distribution for a group of patients should be used for controlling the conditions of mammography screening.
4. By conditions of mammography screening one should understandnot only the quality control of equipment, but also the education and training of the personnel.
5. The analysis of histograms is also required when the automatic optimisation of contrast (AOC) systems is used.
6. In all practical terms the proposed procedures for analogue mammography allow to reduce the absorbed dose to the patient.

Professor Jerzy Tołwiński MD, PhD
Medical Physics Department
Maria Skłodowska-Curie Memorial Cancer Center
and Institute of Oncology
Roentgena 5, 02-781 Warsaw, Poland

References

1. Faulkner K. Mammography screening: Is The Benefit Worth The Risk? Materials of the *11 International Congress of the International Radiation Protection Association*; 23-28 May 2004, Madrid, Spain. Available from: www.irpa 11. com.
2. NCRP Scientific Committee 72 on Radiation Protection in Mammography. A Guide to Mammography and Other Breast Imaging Procedures. Recommendations of the National Council on Radiation Protection and Measurements. NCRP Report No 149. Bethesda: NCRP; 2004.
3. Zoetelief J, Fitzgerald W, Leitz W, Saebel M. European Protocol on Dosimetry in Mammography. Luxembourg: Office for Official Publications of the European Communities; 1996.
4. Woundenberg van S, Thijssen M, Young K. European protocol for the quality control of the physical and technical aspects of mammography screening. In: Perry N, Broeders M, de Wolf C, Tornberg S (eds). *European guidelines for quality assurance in mammography screening.* 3rd ed. Luxembourg: European Communities; 2001.
5. American College of Radiology. Committee of Quality Assurance in Mammography. Mammography quality control manual. Reston: ACR; 1992 and 1999.
6. Fabiszewska E, Tołwiński J, Gwiazdowska B. Dose optimisation in mammography. *Polish J Med Phys Eng* 1996; 4: 19-25.
7. Fabiszewska E. *Optymalizacja parametrów aparaturowych w badaniach mammograficznych.* Ph.D. dissertation. Warszawa: Centrum Onkologii – Instytut im. Marii Skłodowskiej-Curie; 2003.