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MEAN GLANDULAR DOSE IN SIX DIGITAL MAMMOGRAPHY SERVICES IN SANTIAGO, CHILE: PRELIMINARY REFERENCE LEVELS

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The purpose of this paper was to estimate mean glandular dose levels (D_G) in six digital mammography systems in Santiago, Chile, and to propose preliminary reference levels to execute mammography in Chile. The study was carried out assessing two direct digital systems and four computer-based radiography (CR) systems. Estimates of D_G were calculated for different thicknesses of polymethyl methacrylate according to the quality control protocol in digital mammography of the Spanish Society of Medical Physics and NHSBSP Equipment Report 0604 Version 3. D_G values ranged between 0.64 and 7.26 mGy for a range of 20- to 70-mm thickness, respectively. Thirty-six per cent of D_G was higher than the acceptable dose level and 100 % of D_G was higher than the desirable level. It is therefore necessary to optimise doses. The initial proposal to establish dose reference levels for D_G would range between 0.90 and 6.40 mGy for a thickness range of 20 to 70 mm.

INTRODUCTION

Mammography is currently considered to be the best tool for early detection of breast cancer. The target groups of most of the population-based screening programmes are women aged between 50 and 65 y[(1)]. One of the major changes in medical practice is the addition of digital technology in radiological procedures. Currently in use are direct and indirect digital mammography and computed radiography (CR), which have rapidly replaced the traditional screen/film system, as digital systems offer some advantages[(2, 3)].

According to the Chilean Ministry of Health, mortality records in Chile until 2003 for breast cancer[(4)] establish that this disease is the second highest cause of death in the female population. Since 2009, the national breast cancer programme has provided a free mammogram every 5 y to women aged between 50 and 54 y[(5)].

The effectiveness of the mammography procedure essentially depends on diagnostic quality, the application of a quality assurance programme being necessary for the efficiency and safety of this technique[(6, 7)].

These protocols provide the tool to obtain diagnostic image quality with a reasonable dose (the ALARA concept)[(7)]. One quality control test as part of a quality assurance programme is the measurement of dose, a fundamental aspect to consider in optimising the practice. The dosimetric quantity that best characterises the carcinogenic risk induced by ionising radiation in mammography is mean glandular dose (D_G)[(8–10)].

This paper shows D_G results in six mammography units in Santiago, Chile, with the purpose of obtaining the dose levels patients have received and producing an initial proposal to establish reference levels in mammography in the country.

MATERIALS AND METHODS

This study assessed the D_G in six digital mammography systems, composed of two direct digital (DR) and four CR systems. The DR systems belonged to the Hologic Selenia model. All CR systems used a Fuji Profect One digitiser together with a Lorad MIV mammography system. Some technical characteristics of these systems are given in Table 1.

The dose was determined using the standard clinically selected exposure factors. This was done using Automatic Exposure Control (AEC). At the CR units, exclusively the auto-time mode and the molybdenum/molybdenum (Mo/Mo) anode/filter combination was used. The DR systems are capable of automatically selecting the filter and the tube voltage. In this study, the DR systems only used the auto-time mode, allowing comparison to the studies conducted in Brazil by Dantas *et al.*[(11)] All the measurements were made with compressor and grid.

Table 1. Characteristics of mammographic systems.

Systems	Size of pixel μm	Range mAs	Range kV	Anode/filter	Detector technology
Hologic Selenia 1	70	30–170	20–49	Mo/Mo,Rh	DR
Hologic Selenia 2	70	33–180	20–49	Mo/Mo,Rh	DR
Fuji Profect 3	50	24–180	22–35	Mo/Mo,Rh	CR
Fuji Profect 4	50	18–200	22–35	Mo/Mo	CR
Fuji Profect 5	50	18–180	22–35	Mo/Mo,Rh	CR
Fuji Profect 6	50	25–160	22–35	Mo/Mo,Rh	CR

D_G was calculated using polymethyl methacrylate (PMMA) blocks of 180 × 240 mm with thicknesses of 20, 30, 40, 50, 60 and 70 mm. The difference between PMMA and real breast was corrected by adding expanded polystyrene blocks to the PMMA as a spacer to make up a total thickness equal to the equivalent breast. The methodology used to calculate D_G is based on the quality control protocols in digital mammography of the Spanish Society of Medical Physics and National Health Service Breast Screening Programmes (NHSBSP)[2, 12].

An Unfors Xi MAM dosimetry system, with a specific solid-state detector, was used for the measurement. The uncertainty associated ($k = 2$) with the authors' measurement of mean glandular dose using PMMA mammographic phantom is 12 %[13]. The dosimetry system was positioned on the midline of the detector at 4 cm from the chest wall edge. The incident air kerma was then measured for each PMMA thickness along with the half-value layer, which was delivered by the dosimetry system.

Then, in order to obtain the entrance surface air kerma (ESAK)[12], the following expression was used:

$$\mathrm{ESAK} = \frac{K_i}{P_{it}} \cdot P_{it,\,auto} \cdot \left(\frac{d_1}{d_2}\right)^2 \quad (1)$$

where K_i is the incident air kerma, $P_{it,auto}$ is the product of the current by the time obtained with the AEC for PMMA thicknesses and P_{it} is the tube loading used for X-ray tube output calculation. The distances from the focus to the dosimetry system and the surface of PMMA are d_1 and d_2, respectively.

The D_G calculations[2, 12, 14] were made using the following equation:

$$D_G = \mathrm{ESAK} \cdot g \cdot c \cdot s \quad (2)$$

where ESAK is the ESAK (without backscatter) calculated at the upper surface of the PMMA (Equation 1). The coefficient g corresponds to a breast with a glandularity of 50 %. The coefficient c corrects for the difference in composition of typical breasts from 50 % glandularity, and the coefficient s corrects for any difference due to the choice of X-ray spectrum.

RESULTS

Table 2 shows D_G results for different PMMA thicknesses, the beam quality (BQ) for each mammography system and the desirable and acceptable European reference levels[2, 8] associated with good practice.

Table 3 shows the D_G results for this and other studies conducted in different countries. This survey used the same methodology as Dantas *et al.*[11] and Oliveira *et al.*[15]. In the paper of Young *et al.*[16], D_G was measured using PMMA phantoms simulating breasts with thicknesses from 20 to 90 mm. Hendrick *et al.*[17] and the IAEA TECDOC 1646[18] studies were performed with patients with breasts between 40 and 60 mm of thickness.

Table 4 provides an initial proposal to establish reference doses for D_G for mammography procedures in Santiago, Chile. Preliminary reference levels for each PMMA thickness were calculated using the 75th percentile.

DISCUSSION

In Table 2, 100 % of the D_G showed higher than desirable levels of dose and 36 % of the D_G were above the acceptable level. The doses ranged between 0.64 and 7.26 mGy for 20 and 70 mm of thicknesses, respectively. Table 2 shows that the average D_G is greater than the acceptable level for 40 and 50 mm of thicknesses, with a dose of 2.21 and 3.33 mGy, respectively. This implies that certain centres are within the reference levels for a given thickness whereas others exceed those levels, showing the potential for optimisation.

In Table 1, Facilities 1 and 2 correspond to the DR system. There are several publications where the DR system has a significantly lower dose than CR systems, and even a lower dose than film/screen systems. Nevertheless, in this study, the systems indicate very similar doses. The authors believe this is due to the DR calibration system. Many papers show[16–20] that spectral change occurs for 50 mm of thickness and, in this

Table 2. Mean glandular dose for different thicknesses of PMMA, facilities and beam quality (BQ).

PMMA (mm)	20	30	40	50	60	70
BQ (kV)	26	27	28	30	32	32
Hologic Selenia 1	0.81	1.69	2.49	3.35	4.18	5.84
Hologic Selenia 2	1.08	1.66	2.49	3.34	4.17	6.17
Fuji Profect 3	0.83	1.25	2.11	3.27	3.91	6.40
Fuji Profect 4	0.64	1.12	1.86	3.89	4.42	7.26
Fuji Profect 5	0.91	1.35	2.36	3.36	4.17	6.24
Fuji Profect 6	0.85	1.25	1.93	2.75	3.90	5.66
Average	0.85	1.39	2.21	3.33	4.12	6.26
75th percentile	0.90	1.58	2.46	3.36	4.17	6.36
Range (min–max)	0.64–1.08	1.12–1.69	1.86–2.49	2.75–3.89	3.90–4.42	5.66–7.26
EP[a] acceptable	1.00	1.50	2.00	2.50	3.00	4.50
EP[a] achievable	0.60	1.00	1.60	2.00	2.40	3.60

Only Mo/Mo anode/filter combination was used.
[a]European protocol.

Table 3. Comparison of the D_G (mGy) for digital mammography with other studies.

PMMA (mm)	20	30	40	45	50	60	70
This study	0.85	1.39	2.21	2.77	3.33	4.12	6.26
Dantas (CR)[11]	0.73	1.09	1.79		2.47	3.49	5.31
Young (CR)[16]	0.50	0.69	1.12	1.46	1.38	2.22	3.43
Young (DR)[16]	0.70	1.08	1.27	0.99	1.24	1.78	2.63
Hendrick (DR)[17]				1.86			
Oliveira film[15]				1.50			
TECDOC 1646 film[18]				2.21			
EP[a]	1.00	1.50	2.00	2.50	3.00	4.50	6.50
Acceptable and Achievable[8]	0.60	1.00	1.60	2.00	2.40	3.60	5.10

[a]European protocol.

Table 4. Preliminary reference levels for mammography D_G in Santiago, Chile.

Thickness PMMA (mm)	Thickness equivalent breast (mm)	Reference levels for D_G (mGy)
20	21	0.9
30	32	1.6
40	45	2.5
45	53	2.9
50	60	3.4
60	75	4.2
70	90	6.4

paper, it is only obtained from 70 mm, emphasising the optimisation potential.

There are few studies on dose in digital mammography in the region, particularly with the use of different PMMA thicknesses[11] (see Table 3). D_G values for this study were 35 % higher than those obtained by them. Even though the D_G averages are higher, the dose ranges found in this study are contained in the range of doses obtained by Dantas *et al.*[11], which ranged from 0.39 to 11.96 mGy for 20 to 70 mm, respectively. This shows a consistency in the data found in the region. According to Dantas *et al.*[11], 31 % of the D_G data are higher than the acceptable level, compared with 36 % in this study.

Also in Table 3, for the study conducted by Young *et al.*[16], D_G values are set for DR and CR systems associated with different beam qualities and PMMA thicknesses, with results lower than those obtained in this study. The spectra used by Young to irradiate the thicknesses of 20 and 30 mm are similar to those used in this study. However, there are large differences in D_G, which increase with PMMA thickness. The increase in difference is due, among other factors, to the spectra used for thicknesses of >40 mm, which can reduce the dose by >20 %[16, 17, 20]. The study of Young *et al.*[16] observes that systems change the spectrum of Mo/Mo from 30 kV, whereas in this study, the DR systems are calibrated to change its spectrum from 32 kV. This difference in the calibration of AEC also contributes to increasing the dose in the procedures. In fact, the D_G for the DR system with a thickness of 70 mm using a beam of 32 kV Mo/Mo can be reduced by 44 % compared with the dose obtained with a beam of 32 kV Rh/Rh obtained by Young *et al.*[16]

The study by Oliveira *et al.*[15] (Table 3) obtained average values up to 48 % lower than those obtained in this research. Also mention that the dose of CR systems is 60 % higher than the dose values obtained for the screen/film system. Therefore, it is necessary to optimise the digital systems dose to obtain lower dose values than screen/film systems with diagnostic image quality.

The TECDOC 1646[18] study, covering a total of 15 mammography units across 7 Latin American countries, obtained an D_G average of 2.21 mGy (Table 3), a lower value than this study by 20 % compared with the 45 mm of PMMA thickness. The dose range obtained was from 0.72 to 6.56 mGy and 2.81 mGy at the 75th percentile, only 3.4 % less than the 75th percentile of 2.91 mGy calculated in this study, showing consistency with the values found in the region.

The study by Edward Hendrick *et al.*[17] establishes a D_G of 2.37 mGy for conventional mammography and 1.86 mGy for the DR system, 22 % less than the film/screen system. When comparing the authors' results with this[17], higher percentage differences of 26 and 17 % for CR and DR, respectively, were found.

Comparing the results of this study and the values obtained in the literature (Table 3) for both digital and screen/film systems demonstrates that digital technology does not in itself imply a reduction in patient dose, but it is necessary to optimise procedures through the implementation of quality control programmes.

For the DR system, only the Mo/Mo combination was used, to permit comparison with studies conducted in the region[11, 18], when this type of system can use other combinations of target/filter as Mo/Rh, Rh/Rh or W/Rh that could reduce the dose considerably, as seen in the study of Hamed Alizadeh *et al.*[20] where the dose decreased by 26 % by using the combination Mo/Rh for thicknesses of 60 mm and above. The use of the appropriate kV for each breast along with appropriate selection of the anode/filter combination provides an alternative for the optimisation of mammography procedures[19].

The authors' preliminary reference levels would be used as part of the acceptance and optimisation testing of the mammography accreditation programme of the Chilean Society of Radiology (SOCHRADI).

The authors' reference values are higher than those recommended in Europe, so mammographs presenting dose levels higher than this proposal must be considered to be at suspension levels in accordance with the European Protocol EC-162[21]. Dose is not the only parameter in considering the suspension of a mammography system. Systematic monitoring of both image quality and radiation dose is required to guarantee consistently high-quality mammography examinations[1, 22].

Digital technology is gradually replacing conventional film/screen mammography in most countries. Consequently, there is important activity related to developing quality control protocols adapted to these new digital technologies[23, 24]. In this regard, the study by Pissano *et al.*[25] compares the film/screen system and the digital systems, finding that 'the overall diagnostic accuracy of digital and film mammography as a means of screening for breast cancer is similar, but digital mammography is more accurate in women under the age of 50 years, women with radiographically dense breasts, and premenopausal or perimenopausal women'.

In this study, the authors considered both CR and DR technologies. The authors believe that image quality does not necessarily have to be the same. In fact, the study by Hauge *et al.*[26] mentions that the correlation between dose and image quality for DR equipment is not the same, and a study by Mora *et al.*[27] shows that, in Latin America, new technologies have not reduced dose levels and the DRL values for digital DR are higher than those for digital CR equipment. Hence, using the DRL alone as an optimisation tool seems insufficient; one also needs to consider the figure of merit when optimising a system.

In Chile, it is necessary to implement optimisation programmes in mammography as a pragmatic tool in quality assurance programmes. Hence, the authors have chosen the 75th percentile for DRLs because by choosing a 95th rather than a 75th percentile, fewer units would be eligible for optimisation.

The next step is to continue the analysis of digital system images[28, 29] and to show the results of the SOCHRADI accreditation programme. It is expected that doses will be lower than those obtained for digital systems in this study. By investigating the relationship between radiation dose and image quality, DRLs should be established from a better base.

The values obtained in this study provide a basis for an initial proposal to establish reference levels in

mammography in the country (Table 4), a starting point from which future dose results in digital mammography may be compared with optimise dose and develop a national reference in line with the European protocol, which is widely used across many studies conducted in the region.

CONCLUSIONS

Mean glandular dose was calculated in six mammography systems, for different thicknesses of PMMA used in clinical practice. Thirty-six per cent of the calculated mean glandular dose exceeds the acceptable level, and 100 % is above the desirable level according to the protocol used. The variability shown in this research suggests starting an optimisation stage. The preliminary reference levels for D_G vary between 0.90 and 6.40 mGy for a range of 20 to 70 mm of thickness.

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