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Evaluation of DR and CR digital mammography systems based on phantom and breast dosimetry

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Abstract— **Digital mammography has been progressively introduced in screening centers, since recent evolution of CR and DR detectors. However, it is questionable which exposure conditions would be more suitable when these techniques are applied, in order to reduce the glandular breast doses, as they are related with induced carcinogenesis. Several exposures have been performed in CR and DR mammography units for comparing absorbed doses during quality control assessments and during screening, diagnosis and treatment. In the first case, the CIRS11A mammographic phantom has been used with standard exposure conditions (28 kV, AEC mode with blackening +0, 50:50 glandularity and 4.5 compressed breast thickness) in order to obtain reference values for the standard breast. After that, a sample population of 100 women per mammography unit has been registered for performing a dosimetry study during clinical conditions, using the SCREENDOSE software developed by the authors. Results show that there are significative differences among the mammography units, proving that this methodology could be used for obtaining an objective criterion during the selection of a mammography unit, related with a minimum image quality level for a given clinical use (screening, diagnosis or treatment).**

I. INTRODUCTION

Screen-film mammography is nowadays under transition from conventional procedures to digital ones. Digital methods are important due to the possibility of exchange information through a network between centres and the reduction of storing volumes. At the moment, Computed Radiography (CR) and Direct Radiography (DR) are the digital techniques which are being developed in medical applications. The first one uses the same X-ray generator as in conventional radiography, but changing the imaging cassette by a photostimulable imaging plate, which stores the image for being read in a laser scanner afterwards [1]. The DR technique consists on a detector which sends automatically a signal related with the incident and absorbed radiation to a central processor [2].

Nevertheless it is also questionable which exposure conditions would be more suitable when digital mammography is performed [3]. As stated in the European Protocol on Dosimetry in Mammography, the mean glandular breast dose is then a relevant quantity of radiation risk [5]. In this work, a dosimetry study has been performed through a mammographic phantom and several sample populations of exposed women.

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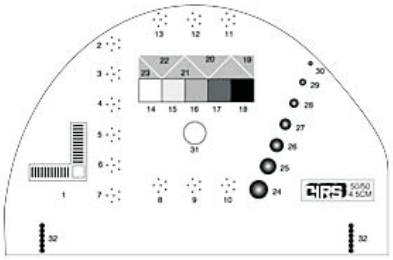

Fig. 1. Scheme of the CIRS 11A mammographic phantom used during quality control assessment

II. MATERIALS

Several digital images have been acquired from the CR and DR mammography equipment of different health centers and units of the Valencian Breast Cancer Screening Program. Table I shows the technology and the mammography equipment of the centres under study.

The CIRS 11A mammographic phantom has been used for testing the exposure conditions and for comparing the mean glandular doses among the different centres. The CIRS 11A mammographic phantom is a 4.5 cm thick mass and it is made up of synthetic resins that simulate the photon attenuation coefficients as breast tissues, with half composition of glandular tissue and the other half of adipose tissue, as described by [4]. Inside the phantom there are several test objects, which simulate, microcalcifications, fibre calcifications at conducts and tumoral masses. Fig. 1 shows a scheme of the CIRS11A mammographic phantom used during quality control assessment.

III. METHODOLOGY

Once all exposures have been performed, several technical parameters have been registered: kilovoltage (kV), compressed breast thickness (4.5 cm of the phantom for every exposure), mAs (miliamperes per exposure time under automatic exposure control mode of the mammography unit). Then, the mean glandular breast dose for every exposure has been calculated with these registered data, assuming a composition of 50% glandular tissue for the simulated phantom.

Several exposures have been performed at every mammography unit using the CIRS 11A mammographic phantom. The conditions during the exposures were:

- Medium optical density, varying tube voltage (26, 28, 30 kV)

TABLE I

DESCRIPTION OF MAMMOGRAPHY EQUIPMENT IN THE CENTRES UNDER STUDY

Centre		Mammography unit	PSP/IP	Scanner
1	CR	SENOGRAPHE DMR (GE)	FCR5000 (Fuji)	FUJI CR Profect CS
2	CR	MAMMODIAGNOSTIC UC (Philips)	CR 75.0 (Agfa)	DRYSTAR 4500M (Philips)
3	DR	SENOGRAPHE 2000 D (GE)	-	-
4	DR	MAMMOMAT NOVATION (Siemens)	-	-
5	DR	LORAD (Agfa)	-	-
6	DR	DM 1000 (Agfa)	-	-

TABLE II

AVERAGE MEAN GLANDULAR DOSES (MSV), ESAK (MGY), HVL (MM AL) AND EXPOSURE PARAMETERS FOR THE CIRS 11A AT 28 KV (BLACKENING +0)

Centre		Γ (mGy m^2/mAs)	HVL (mm Al)	mAs	ESAK (mSv)	MGD (EP)	MGD (MCNP)
1	CR	0.035	0.32	42	4.210	0.848	0.880
2	CR	0.057	0.32	52	9.620	1.678	1.698
3	DR	0.036	0.33	57	5.518	1.139	1.153
4	DR	0.040	0.39	58	8.916	1.519	1.343
5	DR	0.053	0.37	68.8	11.888	2.625	2.488
6	DR	0.059	0.32	58.1	9.511	1.958	1.988

TABLE III

NUMBER OF WOMEN AND VIEWS AND AVERAGE VOLTAGE, TUBE LOADING, COMPRESSED BREAST THICKNESS AND AGE PER SAMPLE PUPULATION

Centre		n. women	n. views	kV	mAs	cm	Age
1	CR	-	100	29 ± 0	42.11 ± 24.32	4.70 ± 1.14	-
2	CR	100	306	29 ± 0	55.83 ± 32.92	4.78 ± 1.30	49.97 ± 14.08
3	DR	100	364	28.33 ± 1.02	70.23 ± 14.85	5.40 ± 0.98	58.01 ± 6.58
4	DR	96	350	27.22 ± 0.56	97.79 ± 38.01	5.57 ± 1.80	54.18 ± 12.48
5	DR	99	326	31.22 ± 1.64	65.21 ± 23.36	6.47 ± 1.29	58.37 ± 12.21

- For a fixed voltage of 28 kV, variation of blackening in three steps (-2, +0 and +2).

IV. METHODS

Mean glandular doses (MGD) have been calculated with conversion factors which converts Entrance Surface Air Kerma (ESAK) for every exposure, following the method proposed in the European Protocol on Dosimetry in Mammography [5] and a Monte Carlo methodology developed by the authors with the MCNP code. In the European Protocol on Dosimetry in Mammography the guidelines for the estimation of mean glandular dose to the breast are described, based on g conversion factors calculated by Dance [6].

In this way, the mean glandular dose to the breast (MGD) is calculated as

$$MGD = gESAK \tag{1}$$

where

$$ESAK = \Gamma \left(\frac{FDD}{FTD - b} \right)^2 mAs \tag{2}$$

where Γ is the incident air kerma per tube loading (mAs) measured at the Foucs Detector Distance (FDD) in mGy/mAs, FTD is the Focus Table Distance and b is the compressed breast thickness. The factor g converts the incident air kerma at the breast entrance to glandular breast dose.

The conversion factor g has been calculated through Monte Carlo simulations with MCNP-4c2, for different compressed breast thickness, glandularity percentage and HVL estimation, using X-ray spectra from the Catalogue of Diagnostic X-ray Spectra and other Data (IPEM) [7]. Mean glandular doses have been obtained using SCREENDOSE software, from conversion factors named above. SCREENDOSE software was developed under Matlab 6 for the calculation of statistics estimators from population samples from exposed women (average value, standard deviation, range, kurtosis) [8]. Fig. 2 shows the comparison between g factor from the European Protocol (-) and that calculated with MCNP4c2 (–) at 28 kV and 0.32 mm Al (50:50). As observed, the methodology is accurate for breast compression thickness larger than 3 cm.

In order to obtain real values of the absorbed doses by exposed women in mammography explorations, a real sample population has been taken from every unit under study. Units 1, 2, 4 and 6 work mainly for breast diseases diagnosis, unit 3 for screening in the VBCSP and unit 5 for

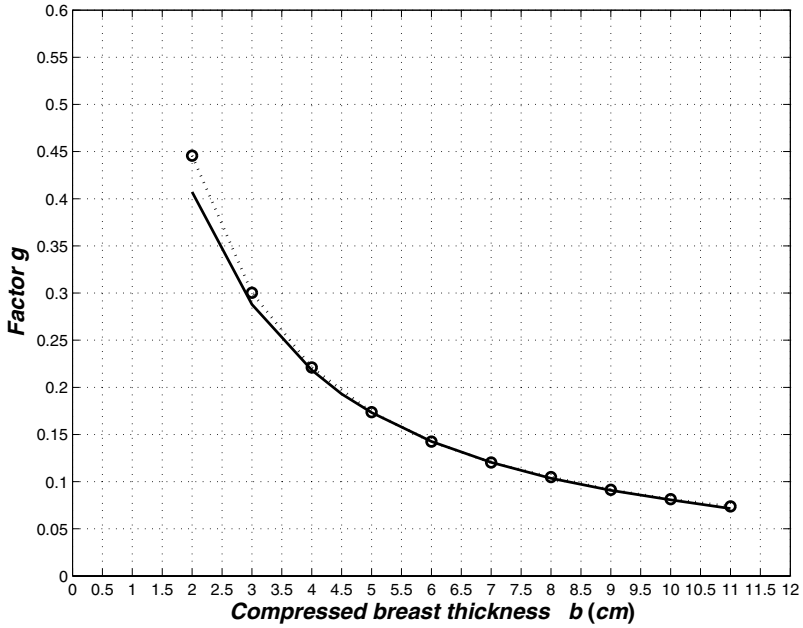

Fig. 2. Comparison of conversion factor from the European Protocol on Dosimetry in Mammography (-) and that calculated with MCNP4c2 (–) at 28 kV and 0.32 mm Al (50:50)

treatment. The sample populations consist of real woman users of the mammography units. In every woman exposure, several data were registered, such as the tube loading in mAs, the compression thickness, tube voltage and projection (CC or OBL) and age. Unit 6 was not available for registering data during the sample registration. Table III shows the statistics of the sample populations per mammography unit. As observed, the main use of the unit is revealed in same statistics, as the average and standard deviation values of compressed breast thickness and women age of units 2, 4 and 5.

V. RESULTS AND CONCLUSIONS

Table II presents the technical-physics parameters obtained during quality control assessment of the digital mammography units and dose results of the exposure. The mean glandular breast doses of a standard 50:50 glandular breast have been calculated from the measurements of the CIRS11A phantom. Table IV shows the average mean glandular doses per each sample population registered in every centre, estimated with the SCREENDOSE software. Results derived from the conversion factors estimated with MCNP-4c2 are slighty similar to dose from the g factor of the European Protocol.

As observed, there are significative differences among incident air kermas at 28 kV and tube loadings due to AEC mode, and consequently different mean gladular doses to the breast in quality control assessment. Furthermore, mean glandular doses derived from sample populations are also consistent with reference results with the phantom, showing a reduction of mean glandular doses in unit 5 compared with unit 4 due to an increment of the compressed breast thickness and kilovoltage and a reduction of tube loading.

TABLE IV
AVERAGE MEAN GLANDULAR DOSES (MSV) PER SAMPLE POPULATION WITH SCREENDOSE SOFTWARE

Centre		MGD (mSv)
1	CR	0.93 ± 0.42
2	CR	1.64 ± 0.76
3	DR	1.33 ± 0.27
4	DR	2.21 ± 0.68
5	DR	2.14 ± 0.67

The results prove that this methodology could be used for obtaining an objective criterion during the selection of a mammography unit, related with a minimum image quality level for a given clinical use (screening, diagnosis or treatment), manteining doses as low as possible.

VI. ACKNOWLEDGMENTS

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