Influence of the dosimeter calibration conditions on the mean glandular dose in mammography

Vivian C R N Bianchi, Claudete R E Silva and Teógenes A Da Silva
Centro de Desenvolvimento da Tecnologia Nuclear, CDTN. Av. Presidente Antônio Carlos 6627, 31270-901 Belo Horizonte, Brazil

silvata@cdtn.br

Abstract. Digital technology in mammography and breast tomosynthesis introduced the use of W and Rh target x-ray tubes with Al, Mo, Rh and Ag additional filters. In Brazil, due to the limited capability of metrology laboratories, x-ray dosimetry in mammography is done with different types of dosimeters that may not be calibrated for such specific clinical beams. The objective of this work was to study the influence of different calibration conditions on the determination of the mean glandular dose in dosimetry in mammography beams.

Keywords: mean glandular dose, dosimeter calibration, dosimetry in mammography

1. Introduction

The x-ray beam with Mo-Mo anode-filter combination was considered ideal for conventional mammography until digital technology and breast tomosynthesis introduced W and Rh target x-ray tubes combined with Al, Mo, Rh and Ag filters.

High quality image in mammography is an obligatory factor to enable good diagnose results. The procedure optimization, traceability and metrological reliability of the instrumentation used for assessing the mean glandular dose, D_G, are essential for the protection of patients undergoing clinical examinations.

The D_G is estimated by determining the incident air kerma at the upper surface of the breast multiplied by factors that are dependent on the breast glandularity, the half-value layer of the beam quality and the energy x-ray spectrum produced by anode-filter combinations. Equation 1 provides details for D_G determination.

\[ D_G = g_t \ c_t \ s \ K_{i,t} \]  

where: \( K_{i,t} \) is the incident air kerma at the upper surface of the standard \( t \) thickness breast, \( g_t \) converts the \( K_{i,t} \) to \( D_G \) for the \( t \) thickness breast with 50% glandularity, \( c_t \) corrects for differences in the glandularity and \( s \) corrects for the difference between the radiation spectra and the Mo-Mo anode-filter combination [1].

Few scientific studies on reference x-ray qualities that are recommended to calibrate dosimeters to be used in dosimetry in mammography have been done in Brazil. Peixoto and De Almeida [2] focused on calibration services as the means for transferring or disseminating SI units and on the implementation of a mammography calibration system using a constant potential x-ray machine. Bastos et al. [3]
investigated the feasibility of the use of a mammography unit to calibrate dosimeters. Pires et al. [4] discussed the conditions and procedures for implementing radiation qualities in a Mo target x-ray equipment. Correa et al. [5] deployed reference x-radiation beams using additional Mo and Al filters.

Nowadays in Brazil, only one metrology laboratory has a Mo-Mo anode-filter x-ray system and the other five reproduce, in limited way, reference radiations based on W target x-ray tubes. Different types of dosimeters as ionization chambers, semiconductors, thermoluminescent dosimeters and radiochromic films have widely been used for dosimetry of clinical mammography beams. In many cases, such instruments were calibrated in reference x-ray qualities that differ from those clinical beams. The objective of this work was to study the influence on the mean glandular dose, $D_G$, which it may be caused by different dosimeter calibration conditions.

2. Materials and methods

2.1. Calibration of the dosimetric systems

The study was done with a RC6-Mt Radcal ionization chamber, a Xi MAM Unfors and an AGMS-M Radcal Accu-Gold semiconductor dosimeters. Dosimeters were calibrated in the CDTN Dosimeter Calibration Laboratory, LCD/CDTN, against a reference Radcal RC6-M ionization chamber traceable to the PTB/Germany through its calibration in Labprosaud/Salvador laboratory. Figure 1 shows the experimental set-up used to calibrate the dosimetric systems in the LCD/CDTN.

![Figure 1 – X-ray Seifert-Pantak set-up used to calibrate dosimeters against the RC6-M standard ionization chamber traceable to PTB/Germany in reference beams for mammography.](image)

Reference beam qualities of 28, 30 and 35 kV for W-Al and W-Mo anode-filter combinations were deployed in an Isovolt Pantak-Seifert x-ray machine and for Mo-Mo in a Mammomat 3000 Nova Siemens unit. Table 1 shows the specification parameters of the reference x-ray beams reproduced in the, LCD/CDTN.
Table 1 – Reference x-ray qualities deployed in the CDTN Dosimeter Calibration Laboratory.

| Beam quality code | Tube potential (kV) | Additional filtration (mm Al) | Half-value layer (mm Al) |
|-------------------|---------------------|-------------------------------|-------------------------|
| W-Al 28 (0.3)     | 28                  | 0.3                           | 0.33                    |
| W-Al 30 (0.3)     | 30                  | 0.3                           | 0.34                    |
| W-Al 35 (0.3)     | 35                  | 0.3                           | 0.38                    |
| W-Mo 28 (0.04)    | 28                  | 0.04                          | 0.29                    |
| W-Mo 30 (0.04)    | 30                  | 0.04                          | 0.31                    |
| W-Mo 35 (0.04)    | 35                  | 0.04                          | 0.33                    |
| Mo-Mo 28 (0.03)   | 28                  | 0.03                          | 0.31                    |
| Mo-Mo 30 (0.03)   | 30                  | 0.03                          | 0.33                    |
| Mo-Mo 35 (0.03)   | 35                  | 0.03                          | 0.36                    |

2.2. Measurement of the mean glandular dose in a mammography unit
The calibrated dosimeters were used to measure the mean glandular dose in 28, 30 and 35 kV Mo-Mo, Mo-Rh and W-Rh combination beams provided by the Mammomat 3000 Nova Siemens unit, according to Equation 1.

For the measurements with the RC6-Mt Radcal ionization chamber the half-value layers, HVL, were determined by the beam attenuation procedure with high-purity aluminium filters; for the measurements with Xi MAM Unfors and the AGMS-M Radcal Accu-Gold dosimeters HVL values directly provided by them were considered.

3. Results

3.1. Calibration coefficients of the dosimetric systems
The calibration coefficients of the RC6-Mt ionization chamber and of the Xi MAN and AGMS-M dosimeters are shown in Table 2; they provided relevant information on the variation of response for different energy spectra for each dosimeter.

Table 2 – Calibration coefficients, $N_K$, of the studied dosimetric systems for W-Al, W-Mo and Mo-Mo reference radiations in the LCD/CDTN.

| Beam quality code | RC6-Mt Radcal chamber (mGy.nC$^{-1}$) | Xi MAM Unfors (mGy/“mGy”) | AGMS-M Radcal (mGy/“mGy”) |
|-------------------|---------------------------------------|---------------------------|---------------------------|
| W-Al 28 (0.3)     | 4.591 (4.1%)*                         | 1.057 (4.1%)              | 0.931 (4.1%)              |
| W-Al 30 (0.3)     | 4.560 (4.1%)                          | 1.038 (4.1%)              | 0.926 (4.1%)              |
| W-Al 35 (0.3)     | 4.604 (4.1%)                          | 1.020 (4.1%)              | 0.938 (4.1%)              |
| W-Mo 28 (0.04)    | 4.620 (2.7%)                          | 0.982 (2.6%)              | 0.930 (2.6%)              |
| W-Mo 30 (0.04)    | 4.699 (2.7%)                          | 1.015 (2.6%)              | 0.938 (2.6%)              |
| W-Mo 35 (0.04)    | 4.641 (2.7%)                          | 1.004 (2.6%)              | 0.886 (2.6%)              |
| Mo-Mo 28 (0.03)   | 4.702 (2.0%)                          | 0.962 (1.9%)              | 1.015 (1.9%)              |
| Mo-Mo 30 (0.03)   | 4.702 (2.0%)                          | 0.974 (1.9%)              | 1.031 (1.9%)              |
| Mo-Mo 35 (0.03)   | 4.702 (2.0%)                          | 0.945 (1.9%)              | 1.006 (1.9%)              |

* Expanded uncertainty for $k=2.$
For the same anode-filter combination, relative to the 28 kV beam quality, the maximum variations of the $N_K$ were 1.7%, 5.2% and 4.7% for the RC6Mt ionization chamber, Xi MAM Unfors and AGMS-M Radcal dosimeters, respectively. Relatively to the Mo-Mo 28 (0.03) beam quality, the maximum variations of $N_K$ were -3.0%, 9.9% and -12.7% for the same dosimetric systems. These results stressed that both semiconductor dosimeters should be calibrated in beam qualities as similar as possible to the clinical x-ray mammography beams.

3.2. Mean glandular dose determined by dosimeters with different calibration conditions
Mean glandular doses, $D_G$, for each beam condition provided by the Mammomat 3000 Nova Siemens unit were determined with the three dosimetric systems. The $D_G$ values determined with the RC6Mt ionization chamber were considered as references for the sake of comparison to the other dosimetric systems due to its low energy dependence in all beam qualities studied.

Figure 2, 3 and 4 show the $D_G$ values determined in the 28, 30 and 35 kV Mo-Mo, Mo-Rh and W-Rh clinical mammography beams considering the calibration of the dosimetric systems in reference radiation conditions.

![Figure 2](image_url) – Mean glandular dose determined in 28, 30 and 35 kV Mo-Mo mammography beams with dosimetric systems calibrated in W-Mo, W-Al and Mo-Mo reference conditions (bars represent the expanded uncertainty for $k=2$).
Figure 3 – Mean glandular dose determined in 28, 30 and 35 kV Mo-Rh mammography beams with dosimetric systems calibrated in W-Mo, W-Al and Mo-Mo reference conditions (bars represent the expanded uncertainty for k=2).

Figure 4 – Mean glandular dose determined in 28, 30 and 35 kV W-Rh mammography beams with dosimetric systems calibrated in W-Mo, W-Al and Mo-Mo reference conditions (bars represent the expanded uncertainty for k=2).
Differences between the $D_G$ values obtained with the Xi MAM Unfors and the AGMS-M Radcal dosimeters relative to the values obtained with the RC6-Mt Radcal ionization chamber are shown in Table 3. $D_G$ were measured in Mo-Mo, Mo-Rh and W-Rh clinical mammography beams supposing that the dosimeters were calibrated in different reference radiation conditions.

| Reference radiation conditions | Difference between $D_G$ values relative to the RC6-Mt Radcal chamber (%) | Xi MAM Unfors | AGMS-M Radcal |
|-------------------------------|-------------------------------------------------------------------------|---------------|--------------|
|                               |                                                                         | Mo-Mo | Mo-Rh | W-Rh | Mo-Mo | Mo-Rh | W-Rh |
| W-Mo 28 (0.04)                | 6.4                                                                     | 13.1  | 13.3  | -4.3 | -0.7  | 0.0   |
| W-Al 28 (0.3)                 | 15.2                                                                   | 19.0  | 13.3  | -3.7 | -2.4  | 0.0   |
| Mo-Mo 28 (0.03)               | 0.1                                                                    | 11.6  | 6.5   | -2.4 | 3.8   | 6.5   |
| W-Mo 30 (0.04)                | 9.2                                                                    | 7.7   | 6.3   | -4.4 | -4.3  | -2.9  |
| W-Al 30 (0.3)                 | 15.1                                                                   | 13.4  | 12.0  | -3.1 | -2.6  | -1.3  |
| Mo-Mo 30 (0.03)               | 4.7                                                                    | 9.2   | 8.1   | 4.6  | 5.1   | 6.5   |
| W-Mo 35 (0.04)                | 10.0                                                                   | 9.9   | 7.9   | -8.9 | -7.3  | -3.6  |
| W-Al 35 (0.3)                 | 12.6                                                                   | 12.6  | 10.5  | -2.7 | -1.1  | 2.7   |
| Mo-Mo 35 (0.03)               | -0.6                                                                   | 8.7   | 6.7   | -0.6 | 3.9   | 8.1   |

Results showed that for the dosimetry of the Mo-Mo clinical beams the maximum differences in the $D_G$ determined by the Xi MAM Unfors dosimeter were 10.0%, 15.2% and -8.9%, -3.7% and 4.6% by the AGMS-M Radcal dosimeter relative to the RC6Mt ionization chamber for the W-Mo, W-Al e Mo-Mo calibration conditions, respectively.

For the dosimetry of the Mo-Rh beams, results showed that the maximum differences in the $D_G$ determined by the Xi MAM Unfors dosimeter were 13.1%, 19.0% e 11.6% and -7.3%, -2.6% e 5.1% by the AGMS-M Radcal dosimeter relative to the RC6Mt ionization chamber for the W-Mo, W-Al e Mo-Mo calibration conditions, respectively.

For the dosimetry of the W-Rh clinical beams, the maximum differences in the $D_G$ were 13.3%, 13.3% and 8.1% for measurements with the Xi MAM Unfors dosimeter and -3.6%, 2.7% e 8.1% for the AGMS-M Radcal dosimeter relative to the RC6Mt ionization chamber for the W-Mo, W-Al e Mo-Mo calibration conditions, respectively.

4. Conclusion
The results of this work showed that, in comparison to a low energy dependent and calibrated ionization chamber, an AGMS-M Radcal semiconductor showed difference in the $D_G$ determination up to 9.0% and a Xi MAM Unfors semiconductor up to 19.0%. Since the $D_G$ expanded uncertainty ($k=2$) was lower than 4.2% for the three dosimetric systems, this work stressed that significant errors in the mean glandular doses can be found during the dosimetry in clinical mammography beams if the dosimetric system was calibrated in reference radiation beams that differ from those. The main source of errors might be the dosimeter energy dependence.
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