Area 14.1: Metrology and instrumentation in ionizing radiations

SPECTRA OF STANDARD MAMMOGRAPHY-QUALITY BEAMS: EXPERIMENTAL MEASUREMENTS AND MONTE CARLO SIMULATIONS

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Abstract: This work presents a spectrometric study of standard mammography-quality beams (the IEC 61267 non-attenuated RQR-M beam series) by using experimental and Monte Carlo simulation methods. The half-value layers calculated from the spectra were compared to those measured with an ionization chamber in the LCR mammography dosimeter calibration setup. The relative differences between the HVLs were lower than 3.1 %. The effective tube voltages were determined from the spectra.

Key words: mammography beams, photon spectrometry, Monte Carlo simulation.

1. INTRODUCTION

A complete characterization of an X-ray beam is achieved by the determination of its photon fluence spectrum [1]. Such information is useful to set up a calibration system in a dosimetry laboratory. In addition, the knowledge about these spectra can help to improve the design of X-ray detectors and the diagnostic imaging techniques. Another reason to obtain these spectra is that the real tube voltage can be accurately determined and compared to that provided by the high voltage generator.

The scope of this work was to carry out a spectrometry study of standard mammography-quality beams by using experimental and Monte Carlo (MC) simulation methods. Specifically, the non-attenuated beams identified as RQR-M series, as described in the IEC 61267 standard [2], were the ones selected for this study.

2. MATERIALS AND METHODS

2.1 Experimental spectrometry and MC simulation

The beams used in this work were produced by a Philips PW 2185/00 X-ray tube with a molybdenum (Mo) target and a beryllium (Be) exit window. Spectra were measured with an Amptek Si-PIN photo-diode (XR-100CR) spectrometer [3]. The measurements were conducted at a source-to-detector distance of 100 cm using a total of 10^6 counts. The energy calibration of the system was carried out using the K_α and K_β peaks of the Mo discrete emissions. The appropriated corrections were applied to the spectra [3, 4].

Monte Carlo simulations were done with the PENELOPE code (v. 2008). The photons arriving at the detector within a 1.5 cm-diameter circumference (~10^6) were post-processed to construct the energy spectra.

2.2 Mean energy, HVL, kVp and uncertainty

The first half-value layer (HVL) for each beam quality was experimentally measured using a Radcal ionization chamber, model 10X5-6M, at the source-chamber distance of 100 cm. The mean energies (E_{mean}) and the HVLs were also analytically calculated from the experimental and simulated spectra. Comparisons between the spectra were made based on these quantities [5].

The experimental spectra obtained in this work were used to determine the effective tube voltage (kVp) used to generate the beams under investigation. About 10 points representing the high-energy of the spectrum were used to find, by a fitting process, the kVps [6].

Uncertainties in the determinations of the E_{mean} were based on Poisson distributions of the counts and of the HVLs on the relationship between the quantities E_{mean} and HVLs. The overall uncertainties stated in this work are reported for a confidence level of 95 % (k=2) [7].

3. RESULTS

The experimental and simulated spectra for the RQR-M2 radiation quality are shown in Fig. 1 (it was chosen the reference quality as example for the four qualities). The data used to plot the experimental spectra of all radiation qualities studied in this work are available on the website of our laboratory (www.lcr.uerj.br/lm/spectra.pdf).

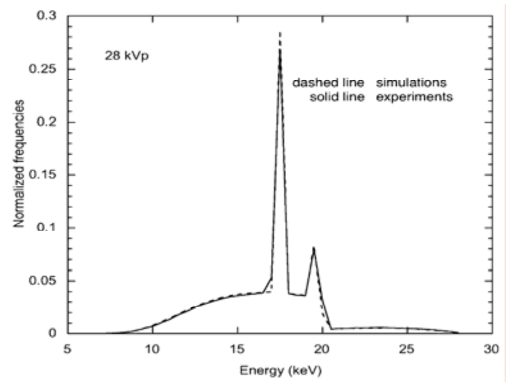

Fig. 1. Comparison between the experimental and simulated spectra obtained in this work for RQR-M2 (28 KV).

The results of the E_{mean} and the HVLs calculated from the measured and simulated spectra are shown in the Tables 1 and 2, respectively. Comparing the HVLs calculated from the simulated spectra and those measured with an ionization chamber the relative differences are lower than 3.1 %.

Table 1. Mean energies (keV) of experimental and simulated spectra, and the relative differences (%) between them.

Quality	kV	Experimental	Simulated	Difference
RQR-M1	25	16.30 ± 0.14	16.16 ± 0.20	0.9
RQR-M2	28	16.92 ± 0.15	16.77 ± 0.20	0.9
RQR-M3	30	17.31 ± 0.15	17.15 ± 0.18	0.9
RQR-M4	35	18.30 ± 0.17	18.05 ± 0.22	1.4

Table 2. HVLs (mm Al) of the mammography-quality beams studied in this work. Values were determined by using an ionization chamber (IC) and calculated from the experimental (Exp.) and simulated (Sim.) spectra. The relative differences (%) between the values calculated from experimental spectra and measured with I.C. are also shown.

kV	IC	Exp.	Sim.	IC-Exp.
25	0.294 ± 0.003	0.291 ± 0.007	0.285 ± 0.011	1.0
28	0.326 ± 0.003	0.322 ± 0.007	0.317 ± 0.010	1.2
30	0.341 ± 0.003	0.340 ± 0.007	0.336 ± 0.008	0.3
35	0.378 ± 0.003	0.380 ± 0.006	0.371 ± 0.007	-0.5

The HVLs calculated from the spectra obtained in this work and those ones measured with the ionization chamber remain within the limits established by IEC [2], as can be observed in Fig. 2.

The calculated spectrum for 30 kV as indicated in the Report 78 of the Institute of Physics and Engineering in Medicine (IPEM) [8] show a HVL 5.6% lower than the value obtained in this work from the experimental spectrum. However, for the same quality, the HVLs measured by Wilkinson *et al* [5] and simulated by Ay *et al* [9] are 2.9 % higher than our result.

The kVp values obtained for the beams qualities RQR-M 1 to 4 were 25.3±0.1; 28.3±0.1; 30.5±0.1 and 35.5±0.1 kV, respectively.

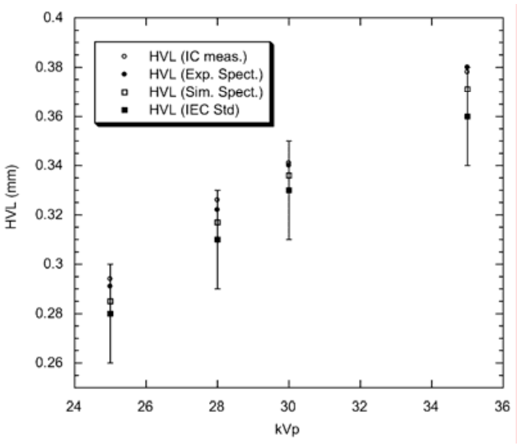

Fig. 2. HVLs obtained in this work from ionization-chamber measurements (IC meas.), experimental spectra (Exp. Spect.) and simulated spectra (Sim. Spect.). The corresponding values and tolerances reported in the IEC standard (IEC Std.) are also shown.

4. CONCLUSION

The maximum difference observed between the HVLs calculated from the experimental and simulated spectra and those measured with the ionization chamber was less than 1.2 and 3.1 %, respectively. This indicates that the methods and parameters used for acquisition, correction and simulation of the spectra were suitable, once the HVL is a quantity very sensitive to changes in energy spectra [3, 6]. The corresponding data of these experimental spectra are available on the LCR website. The methods employed for assess the uncertainties of the E_{mean} and the HVLs are also contributions of this work.

Comparisons with other works showed HVLs higher or lower than the values obtained in this work. The differences in equipment and methods may affect the comparisons even for similar clinical beams. Considering that the HVLs measured and calculated from the experimental spectra obtained in our laboratory remain within the limits established by IEC 61267 [2], the X-ray beams under investigation are similar to those used for clinical purposes.

The experimental spectrometry method was very helpful to determine the kVps of beams used in our metrological laboratory.

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