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Energy dependence evaluation of the patient dose calibrator

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HIGHLIGHTS

- The calibration coefficient of a typical KAP meter significantly depends on the energy distribution of the X-ray beam.
- The energy dependence must be considered in the calibration of KAP meters if good measurement accuracy is desired.
- The energy dependence of the patient dose calibrator (PDC) was determined with the purpose that this equipment will be used to calibrate KAP meters.
- The measurements indicate that the energy dependence of the PDC is small.
- The calibration and the quality control program of the PDC must be considered to evaluate its energy dependence.
- The PDC can be used as reference instrument to calibrate clinical KPA meters especially because of its small energy dependence.

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ABSTRACT

The aim of this paper was to evaluate the energy dependence of the kerma-area product meter Patient Dose Calibrator (PDC). The research was done using the calculation of the coefficient calibration of the air kerma values of different energies that are related to the radiation qualities provided on the International Standard of the International Electrotechnical Commission IEC 61267 for conventional X-rays, mammography and computerized tomography (CT), established at the Calibration Laboratory of IPEN. The calibration was made using reference ionization chambers with traceability to the Primary Laboratory Physikalisch-Technische Bundesanstalt (PTB), Germany. The energy dependence of the PDC was determined and the results showed that the PDC has small energy dependence, less than 6%, for the range of recommended energy while to the mammography range the values were 16% and for CT qualities the dependence was 1%.

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1. Introduction

In diagnostic X-ray equipment the air kerma product (KAP) of the radiation beam is usually measured using a KAP meter with a plane parallel transmission ionization chamber. The calibration coefficient of a typical KAP meter significantly depends on the energy distribution of the X-ray beam; the energy dependence is affected by the materials and design of the chamber. This energy dependence must be considered in the calibration of KAP meters if good measurement accuracy is desired (Toroi et al., 2008).

A KAP meter can be calibrated either in a calibration laboratory or in the clinic and X-ray unit where the meter is used (IAEA—International Atomic Energy Agency, 2007). Standard RQR radiation qualities, intended to represent the X-ray beam incident on the patient in radiographic, fluoroscopic and dental examinations, are generally used for calibration in laboratories, although they do not cover the whole range of radiation qualities used in diagnostic X-ray examinations. To achieve the required accuracy for KAP meters, the calibration coefficients need to be converted to the actual clinical radiation qualities by interpolation using appropriate specifiers of the energy spectrum. The use of a half-value layer (HVL) is generally recommended for this purpose. For reference class ionization chambers, the response depends rather smoothly on the radiation energy, and the HVL is often sufficient for specifying the radiation quality. This is not the case with typical KAP chambers because of their bigger energy dependence (ICRU—International Commission on Radiation Units and Measurements, 2006).

The use of a KAP in clinical department is important to monitor the patient's exposure during the X-ray examination and to achieve a reliable dose evaluation. It also establishes reference levels for examinations. In Brazil, the use of this kind of equipment is not supervised once there is not a recommendation or a procedure determined for its use.

In this work, the energy dependence of the PDC was determined. The purpose of this determination was to use this equipment to calibrate KAP meters in situ once most of these equipments are

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coupled to X-ray units. This is a new equipment from Radcal that measures KAP (Radcal Corporation, 2009). It was manufactured following the IEC 60580 recommendations (IEC—International Electrotechnical Commission, 2000). Its rated range of use for the tube voltage is between 40 kV and 150 kV to conventional diagnostic radiology, but studies have shown that measurements can be done in mammography and CT ranges (Costa et al., 2011).

Calibration coefficients of KAP meters were determined in this study using the radiation qualities RQR, RQT, RQR-M – RQA-M, for diagnostic X-ray units, tomography and mammography, respectively.

2. Materials and methods

2.1. Materials

2.1.1. Patient dose calibrator (PDC)

The PDC, manufactured by Radcal Corporation, USA, operates as a reference meter for field calibration of patient dose analysis and control systems ensuring the validity of inter-institution patient dose comparisons. The PDC is a reference KAP meter and can measure dose, dose rate, dose linearity, air kerma and entrance (skin) dose.

2.1.2. X radiation system

The system used was a Pantak/Seifert located at the Laboratório de Calibração de Instrumentos (LCI) with a voltage up to 160 kV, a tungsten target, a constant potential, an inherent filtration of 0.138 mm Al and a 0.8 mm beryllium window. All the qualities were established according to TRS 457 (IAEA—International Atomic Energy Agency, 2007). The filter wheel has all the specific filtrations used for each radiation quality. For the mammography range, the established radiation qualities were equivalent to the calibration conditions used by the German Primary Laboratory (PTB), with a tungsten target and additional filters of molybdenum to simulate the entrance beams and molybdenum plus aluminum to simulate the exit beams (RQR-M and RQA-M). Fig. 1 shows the X radiation system and the PDC placed in front of it.

2.2. Methods

The PDC was placed in front of the X-ray equipment with the central beam positioned on the PDC's center. All the measurements were done using a current of 10 mA, anode-detector distance of one meter, irradiations of 30 s and five irradiations for each radiation quality. The temperature and pressure were automatically adjusted by the PDC. The standard radiation qualities (IEC—International Electrotechnical Commission, 2000) used were established at the LCI at IPEN. The first measurements conducted were for the mammography range (RQR's-M and RQA's-M). The voltages used were 25 kV, 28 kV, 30 kV and 35 kV. After it, measurements in RQR's range and RQT's range were conducted, representing the ranges of diagnostic radiology and tomography, respectively. Their voltages are 50 kV, 70 kV, 100 kV and 150 kV for the RQR range and 100 kV, 120 kV and 150 kV for the RQT range.

The half value layer (HVL) was used to calculate the effective energy (keV) of each radiation quality. After measuring the air kerma rate with the PDC, the media of the five irradiations was calculated. The reference air kerma rates were established at the LCI using ionization chambers with traceability to the PTB. The traceable ionization chambers models are RC6 for conventional radiology, RC3CT for computerized tomography and RC6M for mammography, all of them manufactured by Radcal Corporation. The calibration coefficient was calculated dividing the reference air kerma by the PDC readings and this result divided again by each reference value (that can be viewed in Table 1 in bold) of the standard radiation qualities for every range studied. Eq. (1) shows how the calibration coefficient was calculated.

$$N_K = \frac{K_{ar}}{M_{PDC}} \quad (1)$$

Where K_{ar} is the reference air kerma and M_{PDC} is the reading values of the PDC for each radiation quality.

IEC 60580 (IEC—International Electrotechnical Commission, 2000), an international standard for KAP meters, allows a combined standard uncertainty of 25% ($k=2$) in KAP measurements under specified conditions, but under more strictly limited conditions, the uncertainty may be reduced. For the energy dependence, the aim of this paper, the standard allows 8% of deviation from the reference value when the total filtration is 2.5 mm and the X-ray tube voltage is between 50 kV and 150 kV. For other filtrations, no requirements are stated in the standard for the calibration coefficient.

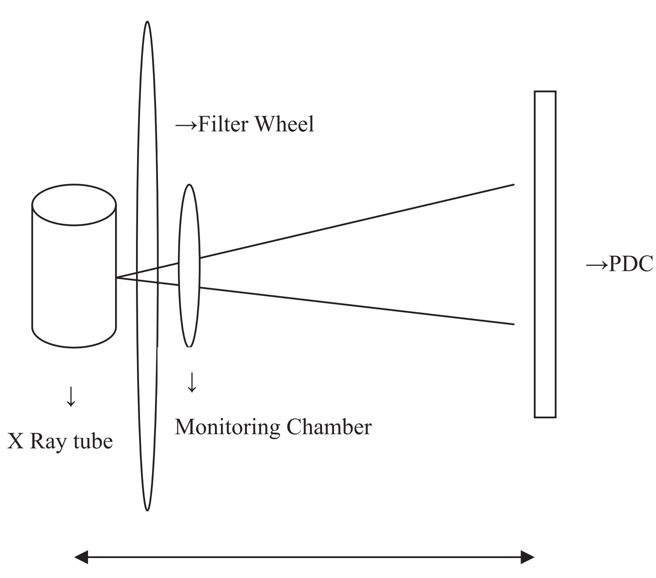

Fig. 1. X radiation system and the PDC positioned as the measurements were done.

3. Results

In Table 1 it is possible to see the results of the obtained values for the ranges studied, as well as their calibration coefficient and the effective energy for each range.

Table 1
Obtained values for the standard radiation qualities.

Radiation qualities	Voltage (kV)	Air kerma rate (mGy/min)	Reference air kerma rate (mGy/min)	Calibration coefficient (Nk)	Effective energy (keV)
RQR 3	50	21.05	22.4	1.06	27.09
RQR 5	**70**	**36.87**	**38.6**	**1.04**	**31.41**
RQR 8	100	68.03	69.3	1.01	37.63
RQR 10	150	121.79	120	0.98	48.41
RQT 8	100	22.2	22	0.99	49.86
RQT 9	**120**	**34.66**	**34**	**0.98**	**56.9**
RQT 10	150	58.96	57	0.96	66.2
RQR-M1	25	6.7	9.78	1.45	15.56
RQR-M2	**28**	**8.5**	**12.2**	**1.43**	**15.7**
RQR-M3	30	9.7	13.83	1.42	15.84
RQR-M4	35	12.9	17.97	1.39	16.25
RQA-M1	25	0.35	0.47	1.34	18.08
RQA-M2	28	0.5	0.67	1.34	18.62
RQA-M3	30	0.7	0.84	1.2	19.35
RQA-M4	35	1.3	1.47	1.13	21.64

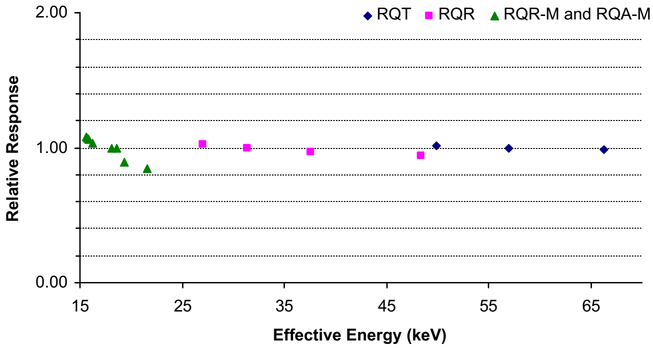

Fig. 2. Energy dependence for the RQT's, RQR's and RQR's-M/RQA's-M.

The measurements indicate that the energy dependence of the PDC is small. Fig. 2 shows this energy dependence graphically. The highest energy dependences were for the RQR's range 6%, for RQT's range 1%, for RQR's-M range 8% and for RQA's-M range 16%. This high percentage for the RQA range is probably because despite the PDC is an equipment that is recommended to be used within 40 kV and 150 kV, its viability using smaller voltages was proved in previous studies (Costa et al., 2011), but it is out of the recommended value. The other quantities are totally acceptable.

4. Conclusion

This study had the aim to evaluate the energy dependence of the patient dose calibrator. It was proved that this instrument has low energy dependence for the recommended energy range described by the manufacturer. For smaller energy ranges, it was shown that the energy dependence is bigger. The calibration and the quality control program of the PDC must be considered to evaluate its energy dependence. Those have already been performed (Costa and Potiens, 2012a, 2012b) and they have shown that the PDC can be used as a reference instrument to calibrate clinical KPA meters.

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