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Calibration of P_{KA} meters against ion chambers of two geometries

Calibração de medidores de P_{KA} contra câmaras de ionização de duas geometrias

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Abstract

Kerma-area product (KAP or P_{KA}) is a quantity that is independent of the distance to the X-ray tube focal spot and that can be used in radiological exams to assess the effective dose in patients. Clinical KAP meters are generally fixed in tube output and they are usually calibrated on-site by measuring the air kerma with an ion chamber and by evaluating the irradiated area by means of a radiographic image. Recently, a device was marketed (PDC, Patient Dose Calibrator, Radcal Co.), which was designed for calibrating clinical KAP meters with traceability to a standard laboratory. This paper presents a metrological evaluation of two methods that can be used in standard laboratories for the calibration of this device, namely, against a reference 30 cc ionization chamber or a reference parallel plates monitor chamber. Lower energy dependence was also obtained when the PDC calibration was made with the monitor chamber. Results are also shown of applying the PDC in hospital environment to the cross calibration of a clinical KAP meter from a radiology equipment. Results confirm lower energy dependence of the PDC relatively to the tested clinical meter.

Keywords: air kerma-area product, dosimetry, calibration, KAP meters, radiology, ionization chambers.

Resumo

A grandeza produto kerma-área (P_{KA}) independe da distância ao foco do tubo de raios X e pode ser usada nos exames radiológicos para avaliar a dose efetiva nos pacientes. Medidores clínicos de P_{KA} são geralmente fixados na saída do tubo e usualmente calibrados no local, por meio da medição do kerma no ar com uma câmara de ionização e da avaliação da área irradiada utilizando uma imagem radiográfica. Recentemente, foi projetado e comercializado um dispositivo para calibrar medidores clínicos de P_{KA} (PDC, *Patient Dose Calibrator* – Calibrador da dose do paciente, Radcal Co.), com rastreabilidade a um laboratório padrão. Este trabalho apresenta uma avaliação metrológica de dois métodos que podem ser utilizados em laboratórios padrão para calibrar tal dispositivo, ou seja, contra uma câmara de ionização de 30 cc de referência ou uma câmara de monitora de placas paralelas. Menor dependência energética foi obtida quando a calibração do PDC foi realizada com a câmara de monitora. São mostrados também resultados do PDC aplicado em um ambiente hospitalar para a calibração cruzada de um medidor clínico de P_{KA} de um equipamento radiológico. Os resultados confirmam menor dependência energética do PDC em relação ao medidor clínico testado.

Palavras-chave: produto kerma-área de ar, dosimetria, calibração, medidor de produto kerma-área, radiologia, câmaras de ionização.

Introduction

Due to the quantity and frequency with which clinical examinations are performed, the dose released in diagnostic radiology and interventional procedures should be accurately determined so as to maintain a reasonable balance between image quality and absorbed dose to patients.

The more appropriate quantity to express, the levels of exposure to radiation is the effective dose (E), which cannot be directly measured[1]. It can however be obtained through the quantity air kerma-area product (KAP or P_{KA}), whose value, by definition, is constant with the distance between focal spot and patient[2].

The issue has special relevance in Brazil, since there are still few national references about the subject[3], reduced clinical use (yet), despite the recommendation of international standards[4], and the need for calibration of P_{KA} meters preferably in Brazil itself, in order to meet the demand that tends to grow soon.

P_{KA} meters differ from common ionization chambers, since in those its sensitive volume is only partially irradiated.

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Therefore, in the P_{KA} meters calibration process, which uses a totally irradiated reference chamber, it is necessary a method to evaluate the irradiated area which results in an undesirable increase of the overall uncertainties.

Recently, a device named PDC (Patient Dose Calibrator, Radcal Co.), which was designed for calibrating clinical P_{KA} meters with traceability to a standard calibration laboratory, was commercialized. This paper had the aim of investigating two methodologies to calibrate the PDC P_{Ka} meter in laboratory, also analyzing the influence quantities in this process, and minimizing uncertainties in such calibration for direct standard X-ray beams[5]: first, against a reference 30 cm^3 ion chamber and, second, against a monitor chamber, crossed by the entire beam, as the PDC. Then, an application was made of cross calibration of a clinical P_{KA} meter using the previously calibrated PDC.

Materials and methods

Used equipment

All experimental work was made in the Laboratory of Ionizing Radiations Metrology (LMRI) of the Instituto de Eletrotécnica e Energia da Universidade de São Paulo (IEE-USP), using its infrastructure. A constant potential Philips X-ray equipment was used, which consists of a bipolar high-voltage generator MG 325 (ripple ≤ 1%), adjustable from 15 to 320 kV, a metal-ceramic tube model MCN 323 with tungsten anode, large focal spot size 4 mm, anode angle of 22°, 4 mm Beryllium window, and a control unit model MGC 40. The beam was collimated by a set of 2 mm thick lead collimators with known apertures, and filtered by 99.0 to 99.5% purity Al sheets. For the P_{KA} determination, a reference collimator, 4.5 mm in thickness and 10.8 cm in aperture diameter, was used near the detector position.

High-voltage waveforms have been invasively acquired by means of the computational acquisition and A/D channel card of a Tektronix TDS5104 oscilloscope, and voltage parameters, such as average peak voltage (kVp_{ave}) and practical peak voltage (PPV, as defined by IEC 61676 standard[6]), have been calculated by a LabView (National Instruments) routine developed at IEE-USP.

Two calibrated detectors have been used for the air kerma measurements: a PTW TN34014 model monitor chamber, with carbon coated surfaces, and a reference PTW 23361 model 30 cm^3 cylindrical chamber, both connected to PTW Unidos electrometers.

Setup alignment was made with the help of an optical bench, laser beams and semi-transparent mirrors. Atmospheric pressure and temperature were measured by an Oregon Scientific Co. calibrated meter in order to correct all air kerma readings by air density influence.

The investigated P_{KA} meter was a Radcal detector model PDC, borrowed by Radcal Co.

Methodology

X-ray beams characterization

The whole set of conventional radiodiagnostic (RQR) standard X-ray beams from IEC 61267:2005[7] has been previously characterized in the Philips equipment, using the reference 30 cm^3 ion chamber and 99.9% purity Al filters for the half value layers (HVL) determinations. First and second HVL values have been obtained by a logarithmic interpolation method between two points measured before and after the HVL corresponding thickness.

kVp_{ave} values from Philips equipment, read with the LabView routine, have been calibrated by means of measured incident beam X-ray spectra obtained with a CdTe spectrometer (Amptek, Inc.) calibrated, in turn, using X- and γ-ray known energies from Am-241 and Ba-133 calibrated radioactive sources. The average value of the maximum spectral energy E (in keV) is numerically equal to the value of the average peak tube voltage (kVp_{ave}, in V), for low ripple voltage waveforms. In this work[8], the endpoint energy E was determined by a least squares linear regression procedure at the higher energy part of each measured beam spectrum. Applying this calibration to the whole voltage waveform, PPV values were determined by its definition[6] with uncertainties lower than 0.5 kV (k=2), for each standard beam.

PDC calibration against 30 cm^3 reference chamber

In these measurements, monitor chamber has only been used for correction of X-ray tube output changes. Using the substitution method, the reference chamber and the PDC meter were alternatively put in the X-ray beam axis, 100 cm distant from the focal spot, in each characterized beam.

Each P_{KA} rate value from PDC (P_{KA}^{PDC}) was obtained as an average of five readings, after correction for air density influence. For the 30 cm^3 chamber, the average air kerma rate (K_{air}^{ref}) was obtained after correction for air density and calibration factor. Aperture area of the reference lead collimator (A_{COL}), placed 8.5 cm in front of the detector, was determined and, thus, the reference P_{KA} rate, P_{KA}^{ref}, was calculated in each case. Calibration factors for P_{KA} rate readings from PDC detector have been obtained by Eq. 1:

$$F_{CAL-PDC\_ref} = \frac{P_{KA}^{ref}}{P_{KA}^{PDC}} = \frac{K_{air}^{ref}}{P_{KA}^{PDC}} \cdot A_{COL} \cdot \left(\frac{d_{FD}}{d_{FC}}\right)^2 \qquad (1)$$

In Eq. 1, d_{FD} and d_{FC} are the distances between focal point and, respectively, reference detector or collimator, which values are 100.0 and 91.5 cm, both with 0.1 cm estimated uncertainty (k=1).

PDC calibration against monitor chamber as reference

In these measurements, a monitor chamber has been moved to a place between detector and reference collimator positions and, firstly, it was calibrated against the cylindrical chamber placed in detector position. After this, the 30 cm^3 chamber was substituted by the PDC in such a way that, in these measurements, the same X-ray beams crossed both detectors simultaneously (Figures 1 and 2).

In the calibration of the monitor chamber (Figure 1), each air kerma rate value from reference chamber, K_{air}^{ref}, or each charge rate value from monitor chamber, Q_{mon}, was obtained as an average of five readings after correction for air density. Calibration factors for monitor chamber charge readings, corrected for distance, in this case, have been obtained by Eq. 2:

$$f_{CAL-Mon\_ref} = \frac{K_{air}^{ref}}{Q_{Mon}} \cdot \left(\frac{d_{FD}}{d_{FM}}\right)^2 \text{(mGy/nC)} \qquad (2)$$

where:

d_{FD} and d_{FM} are the distances between focal point and, respectively, reference detector and monitor chamber, which values were 98.9 and 65.5 cm, both with 0.1 cm estimated uncertainties (k=1).

For the calibration of the PDC against the calibrated monitor chamber (Figure 2), each P_{KA} rate value from PDC, P_{KA}^{PDC}, was also obtained as an average of five readings after correction for air density. The reference values of P_{KA} rate, P_{KA}^{Mon}, have been obtained through the product of average air kerma obtained with the calibrated monitor chamber, K_{air}^{Mon} (= Q_{mon} . $f_{CAL-Mon\_ref}$), and the aperture area of the reference collimator, A_{COL}, corrected for distance. Both P_{KA} values were corrected for air density. Calibration factors for PDC P_{KA} readings, in this case, were obtained by Equation 3:

$$F_{CAL-PDC\_Mon} = \frac{P_{KA}^{Mon}}{P_{KA}^{PDC}} = \frac{K_{air}^{Mon}}{P_{KA}^{PDC}} \cdot A_{COL} \cdot \left(\frac{d_{FM}}{d_{FC}}\right)^2 \qquad (3)$$

where:

d_{FC} is the distance between focal spot and reference collimator, which is 60.7±0.1 cm.

Application of calibrated PDC to verify the calibration of a clinical P_{KA} meter

As application of the PDC detector, after calibration, a calibration checking of a clinical P_{KA} meter (Scanditronix-IBA) coupled to a Philips Omni X-ray equipment, from Hospital Israelita Albert Einstein (HIAE), in São Paulo, was carried out. The PDC was supported 17 cm over the exams table, at a distance of 80.5 cm from the X-ray tube focal spot (Figure 3). The exposure times were 200 ms.

P_{KA} values were measured with both detectors simultaneously irradiated, in a series of measurements with the following conditions: tube voltage varying from 50 to 120 kV, current-time product fixed as 50 mAs, for three radiation fields sizes (15x15, 20x20 and 25x25 cm^2), adjusted by means of the tube collimator.

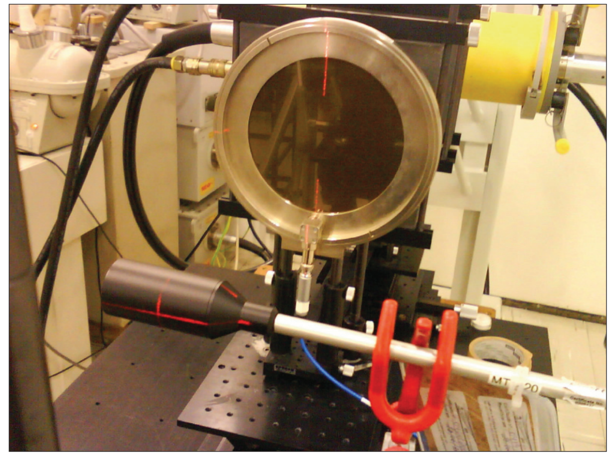

Figure 1. Positioning of reference 30 cm^3 chamber and graphite coated monitor chamber in the monitor calibration procedure.

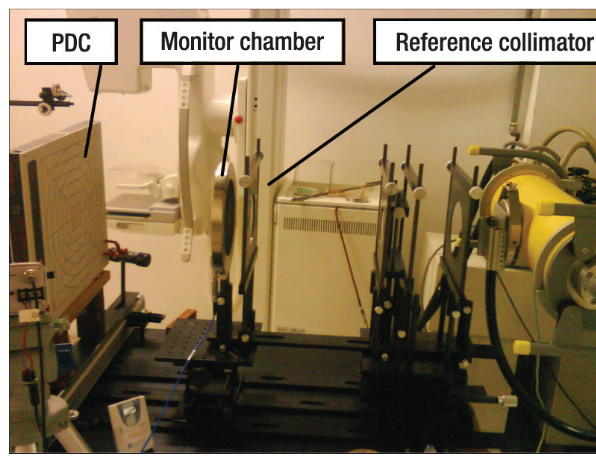

Figure 2. Experimental setup showing the relative positions of PDC and monitor chamber used as air kerma reference, as well as the reference collimator.

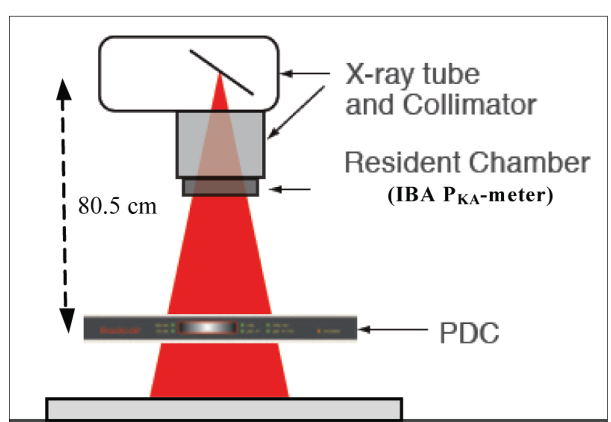

Figure 3. Scheme of setup used for the simultaneous measurements made with the PDC and the Scanditronix-IBA P_{KA} meter (coupled to a Philips Omni X-ray equipment), in the clinical environment of HIAE (illustration adapted from www.radcal.com).

Results

PDC Calibration factors against cylindrical chamber

Figure 4 shows the obtained data of the PDC calibration factors versus the PPV for air kerma and air kerma-area product quantities, which were obtained from the measurements against the cylindrical reference chamber.

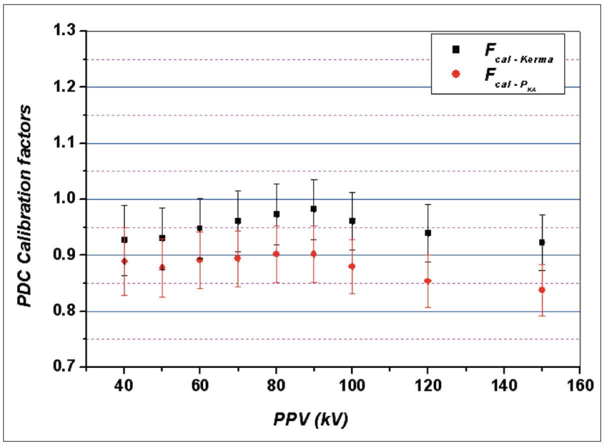

Figure 4. Energy dependence curve of PDC detector versus PPV values, for P_{KA} and K_{air} values, measured against the reference 30 cm^3 chamber, for RQR standard beams[7]. All error bars are shown for k=1.

Table 1. Average air kerma rate values (K_{air}^{ref}) from reference 30 cm^3 chamber and charge rate values (Q_{Mon}) from monitor chamber (corrected for reference chamber position), as well as the obtained monitor chamber calibration factors ($f_{CAL\text{-}Mon\_ref}$), for three standard direct beams

Standard beam	PPV (kV)	K_{air}^{ref} (mGy/min)	Q_{Mon} (nC/min)	$f_{CAL}^{Mon\_ref}$ (mGy/nC)
RQR3	49.99(9)	25.5(7)	69.8(2)	0.37(1)
RQR6	80.00(12)	58(2)	159.9(4)	0.37(1)
RQR9	120.07(17)	124(3)	335.3(8)	0.37(1)

Table 2. Values of air kerma-area product rate (P_{KA}) (a) and air kerma rate (K_{air}) (b) measured with PDC and determined from calibrated monitor chamber and reference collimator, as well as the obtained PDC calibration factors ($F_{CAL}^{PDC\_Mon}$), for the same three standard beams above.

	Standard beam	P_{KA}^{PDC} (mGy.m²/min)	P_{KA}^{Mon} (mGy.m²/min)	$F_{CAL\_PKA}^{PDC\text{-}Mon}$
a	RQR 3	0.63(5)	0.62(4)	0.98(9)
	RQR 6	1.41(10)	1.43(8)	1.02(9)
	RQR 9	3.11(22)	3.03(17)	0.97(9)
	Standard beam	K_{air}^{PDC} (mGy/min)	K_{air}^{Mon} (mGy/min)	$F_{CAL\_K}^{PDC\text{-}Mon}$
b	RQR 3	0.064(3)	0.058 (3)	0.91(5)
	RQR 6	0.141(7)	0.134(7)	0.95(5)
	RQR 9	0.31(2)	0.28(2)	0.91(5)

PDC Calibration factors against monitor chamber

Table 1 shows the obtained results of the calibration factors for the monitor chamber against the cylindrical chamber. In Table 2, we have the results of the PDC calibration made against the calibrated monitor chamber as the reference detector, for the same characterized standard beams. Uncertainties appear between brackets to show only the less significant figure.

Verification of calibration of the clinical P_{KA} meter using the calibrated PDC

Figure 5 shows the results obtained from measurements made with PDC and the Scanditronix-IBA P_{KA} meter coupled to Philips Omni X-ray equipment, for some field sizes. The P_{KA} values showed by the two meters, obtained in a clinical setting in HIAE, were not corrected for air density effects, since they were not monitored for temperature and pressure at the site. Linearity of both meters were checked all over the investigated intensities range (up to 700 μGy.m²), and R-coefficient was better than 0.999.

Conclusions

It is possible to verify that uncertainties in calibration factors are lower for the PDC than for clinical P_{KA} meters like the investigated ones[9]. Indeed, uncertainties reached a maximum of 13% for PDC and 24% for the Scanditronix-IBA meter (k=2) (both calibrated against the cylindrical PTW reference chamber). These results are in accordance with IEC 60580:2000 standard[10], which recommends uncertainties up to 25%.

Also, the energy dependence of PDC was lower than that of the clinical P_{KA} meter: calibration factors showed deviations from -10 to -16% for the PDC, and from -1 to +16% for the other one. For the IBA meter, calibration factors showed an increasing trend with tube voltage for all analyzed radiation field sizes[9]. This difference can be

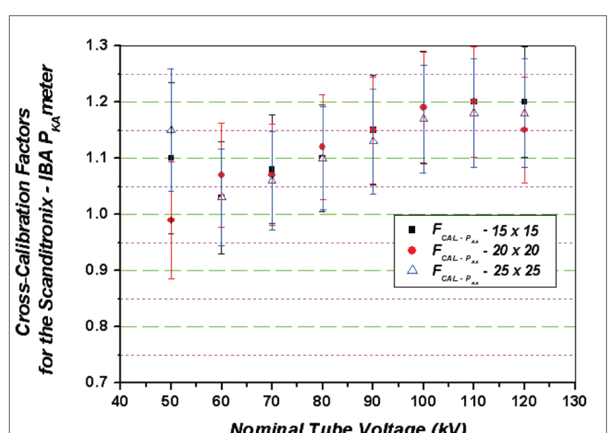

Figure 5. Energy dependence curve of the Scanditronix – IBA detector, showing P_{KA} versus nominal kVp values, for three sizes of radiation field (triangle = 25x25 cm², circle = 20x20 cm² and square = 15x15 cm²), measured against the calibrated PDC.

attributed to the lower atomic number of components of PDC incidence surface, compared to the clinical meters, which need to be transparent.

Comparing the two methods of calibration of PDC in a calibration laboratory, although the energy dependence has remained, the difference among values of the determined calibration factors is clear: with monitor chamber, PDC calibration factors varied only from 0.97 to 1.02 (Figure 4 and Table 2). The radiation field that reaches the 30 cm^3 chamber, used as reference, is not the same incident onto the PDC surface, covering only the central portion of the beam. Unlike, putting the monitor chamber, as reference, after the reference collimator, the X-ray beam passing through the chamber will be nearly the same incident on PDC surface. The beam that reaches the cylindrical chamber is a little harder than the incident on the PDC surface.

It becomes also evident in the air kerma results. Air kerma is measured by a 10x10 cm^2 chamber located at the center of PDC. Thus, the beam impinging its surface is like the one that reaches the cylindrical chamber volume and so the calibration factor is closer to the unity.

In addition, transmission chambers that are not optically transparent (graphite-coated chambers, for example, like the used monitor chamber) may be more appropriate to be used as reference chambers, because they have less energy dependence.

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