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QUALITY CONTROL TESTS FOR CALIBRATION OF KAP METERS.

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Abstract: In accordance with IEC 60580:2021, KAP meters are typically calibrated using cylindrical reference ionization chambers aligned with RQR radiation qualities specified by ISO 61267. However, discrepancies in manufacturing geometry between these reference chambers and PKA meters prompted a series of quality control tests to establish an effective calibration methodology. Two distinct tests of quality control were conducted to compare the performance of a reference KAP meter (PDC - Radcal®) with a reference ionization chamber (Radcal® 10x5-180), using the Agfa® PANTAK Constant Potential X-Ray System. These tests included homogeneity assessments with varying horizontal displacements of the reference PDC meter and reproducibility tests at consistent positions. The two tests were conducted for Kerma and PKA unities. A third test is still in progress, the long-term stability, with repeated measurements; as with the tests ago, for Kerma and KAP measurements. These results demonstrated good correlation and traceability between the PDC and the ionization chamber, with reproducibility and homogeneity within an uncertainty margin below 3 %. These findings validate the proposed calibration method for practical applications.

Keywords: PKA Meters Calibration, Ionizing Radiation Metrology, Quality Control Tests, Dosimetry Systems.

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TESTES DE CONTROLE DE QUALIDADE PARA CALIBRAÇÃO DE MEDIDORES DE PKA.

Resumo: De acordo com a IEC 60580:2021, os medidores de KAP são tipicamente calibrados usando câmaras de ionização de referência cilíndricas, conforme as qualidades de radiação RQR especificadas pela norma ISO 61267. No entanto, discrepâncias na geometria de fabricação dentre as câmaras de referência e os medidores de PKA levaram à realização de uma série de testes de controle de qualidade para estabelecer uma metodologia de calibração eficaz. Foram realizados três testes distintos para comparar o desempenho de um medidor de KAP de referência (PDC - Radcal®) com uma câmara de ionização de referência (Radcal® 1610), utilizando o Sistema de Raios X PANTAK de Potencial Constante. Esses testes incluíram avaliações de homogeneidade, com deslocamentos horizontais variados do medidor de referência PDC e testes de reprodutibilidade em posições consistentes. Os dois testes foram realizados para as grandezas Kerma no ar e para PKA. Um terceiro teste ainda está em andamento, o de estabilidade ao longo do tempo, com medidas repetidas; e como nos testes anteriores, para medidas de Kerma e KAP. Esses resultados demonstraram uma boa correlação e rastreabilidade entre o PDC e a câmara de ionização, com reprodutibilidade e homogeneidade dentro de uma margem de incerteza abaixo de 3 %. Esses achados validam o método de calibração proposto para aplicações práticas.

Palavras-chave: Calibração de Medidores PKA, Metrologia de Radiações Ionizantes, Testes de Controle de Qualidade, Sistemas de Dosimetria.

1. INTRODUCTION

Dosimetry in diagnostic radiology and radiation protection is crucial for maintaining accuracy standards and ensuring safety. The guarantee of accuracy in methodology of calibration process is crucial, and it is obtained by maintaining the quality control of dosimetry equipment, to ensure reliable results (Costa, 2013 [1]; Costa and Potiens, 2013 [2]). One of these equipment is the patient dose calibrator (PDC), in Figure 1, applied to measure Kerma-Area Product (KAP), largely used in procedures of interventional cardiology (Vano, *et al,* 2019 [3]), and in radiography of chest (Delakis and Kelly, 2021 [4]).

Figure 1: Patient Dose Calibrator (PDC), with attached support, displayed at vertical position.

Source: Radcal® user's manual [3] (at https://radcal.com/downloads-manuals/)

The quality control of dosimetry equipment is guaranteed by the quality control tests and by the calibration of equipment. These tests are essential to estimate correctly other quantities, such as Entrance Surface Air Kerma (ESAK), used at many exams of digital radiology and fluoroscopy (Suliman, 2022 [5]).

Typically, KAP meters are calibrated using a reference ionization chamber, such as a cylindrical ionization chamber conforming to IEC 60580:2021 [6]. This reference chamber is calibrated to specific radiation qualities (RQRs) recommended by the ISO 61267 standard [7]. However, these reference chambers have a significantly different design than KAP meters (Almeida Jr., et al, 2013) [8]. Therefore, rigorous quality control measurements are required to ensure the effectiveness of the calibration methodology. To justify the accuracy and reliability of the calibration process, the authors implemented a series of quality control tests.

2. OBJECTIVE

To assess the performance and establish a reliable calibration methodology for KAP meters, reproducibility and homogeneity tests were conducted using a reference KAP meter (PDC - Radcal®) and a reference ionization chamber (Radcal®, model 10x5-180) on a Constant Potential X-Ray System (Agfa PANTAK®). The implemented quality control tests will be used to support the calibration methodology for KAP meters.

3. MATERIALS AND METHODS

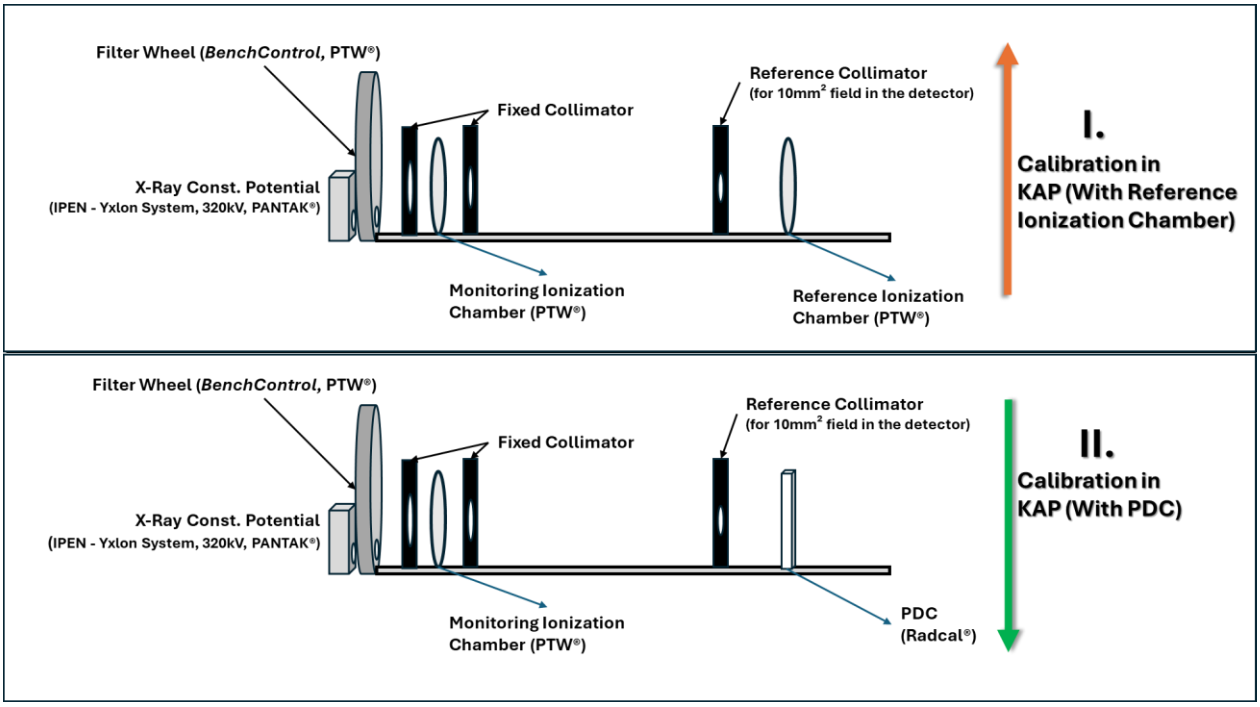
3.1. Calibration Methodology

To determine calibration methodology, two different types of quality control tests were carried out, comparing the performance of a reference KAP meter (*Patient Dose Calibrator,* PDC - Radcal®) with a reference ionization chamber (Radcal®, model 9010 with conversor model 9060 and ionization chamber model 10x5-180 (Radcal, 2016) [9]), using the PANTAK Constant Potential X-Ray Yxlon System (Agfa PANTAK®).

The use of this model of reference ionization chamber is because of its purpose in diagnostic radiology, used for leakage current and low-level measurements, which cases this chamber could be used as reference ionization chamber (with calibration accuracy of ±4 %, at 150 kVp) [9]. Additionally, this ionization chamber has a sensitive volume of 180 cm^3 and an effective cross-section of 100 cm^2. Comparing dimensions, this chamber is more similar to a typical KAP meter (aprox. 140 x 140 mm), than a cylindrical reference ionization chamber (6 cm^3).

In Figure 2, the method of calibration by substitution technique is shown. This method was utilized to calibrate PDC: at the same position (Figure 2, I) that the reference Ionization Chamber (Radcal®, model 10x5-180) is calibrated for KAP, so, the PDC is calibrated (Figure 2, II), under the same condition of temperature and pressure.

Figure 2: Geometry, not to scale, utilized to calibrate the PDC by the substitution method, with PDC (II) at the same position that reference ionization chamber (I).

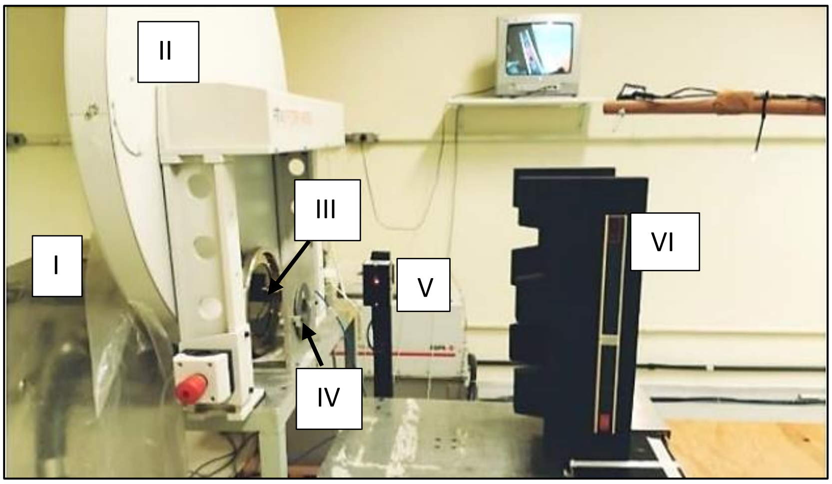


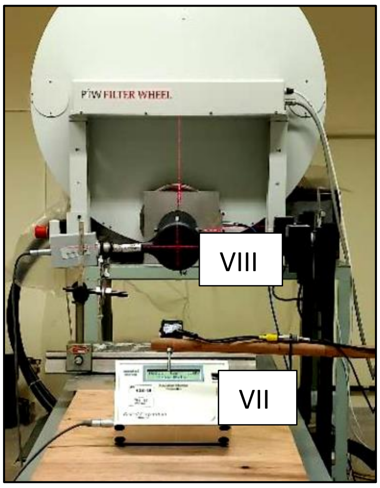
Source: Author's diagram.

The calibration with substitution technique were performed with PDC and ionization chamber at the same distance and measurements with the X-Ray system (Agfa PANTAK

Constant Potential System) (Figure 3). In Figure 3a, I. Constant Potential X Ray System (Agfa Yxlon system, PANTAK® Isovolt); II. PTW® filter wheel; III. Monitor ionization chamber (PTW® model 34014); IV. Colimator of 5.08 cm diameter, for diagnostic radiology; V. Laser system for alignment; VI. PDC (Radcal®); VII. Converter model 9060 for VIII. Reference Ionization Chamber Radcal®, model 10x5-180.

Figure 3: Set up utilized to calibrate (a) PDC by (b) reference chamber, both at same position, by the substitution technique.

a)


b)


Source: Author images

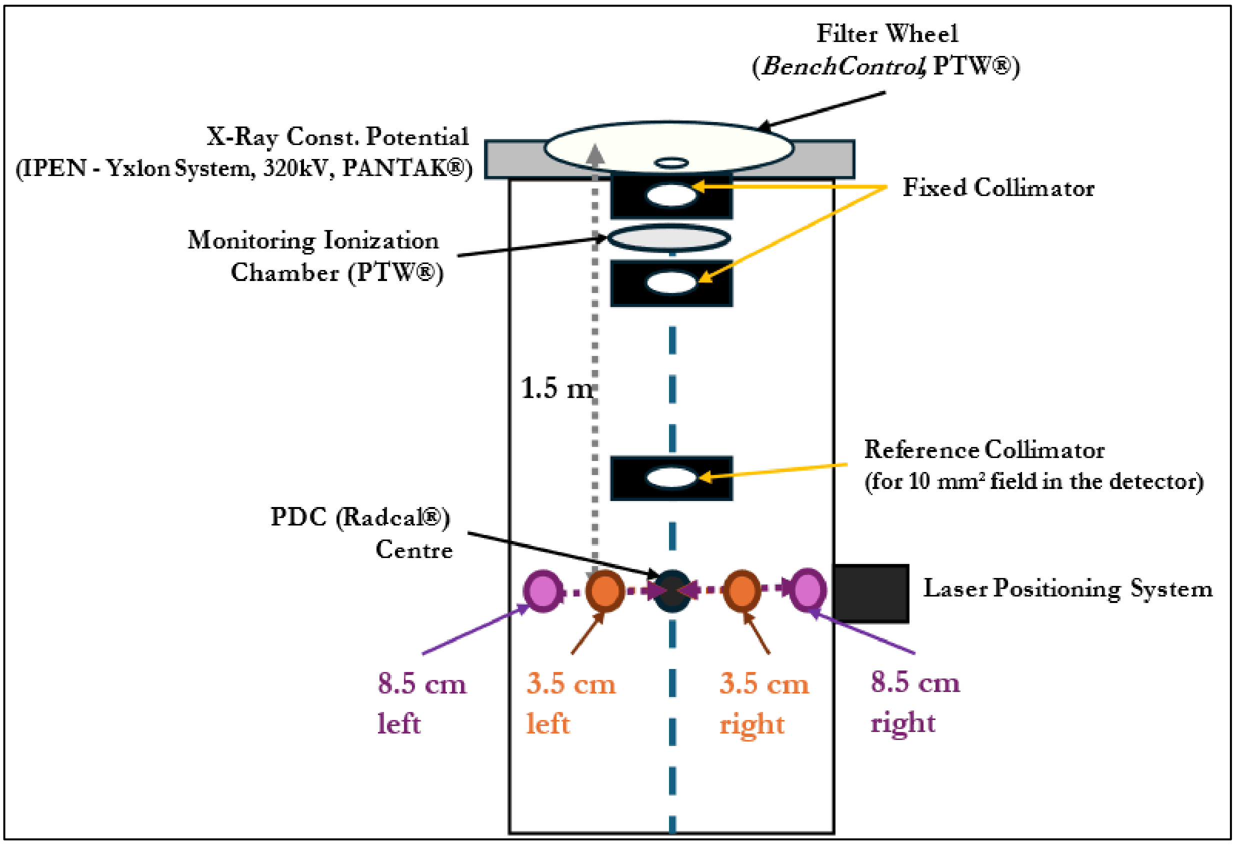
As soon as the PDC (Radcal®) was calibrated, it is used in the quality control tests.

3.2. Quality Control Tests

Two tests were performed, comparing the PDC (Radcal®) against reference ionization chamber (Radcal®), aiming to guarantee repeatability and reproducibility in the equipment tested.

In **Homogeneity Test**, PDC were displaced 3.5 cm and 8.5 cm, to the right and to the left (in both cases), to evaluate the KAP for the IEC X-ray qualities RQR 3, RQR 5, RQR 8 and RQR 10, as shown in Figure 4.

Figure 4: Front view, of the set up (not to scale) for the *Homogeneity Tests* - PDC were displaced 3.5 cm and 8.5 cm, to the right and to the left (in both cases), to evaluate the KAP for the IEC X-ray qualities.



Source: Author's diagram.

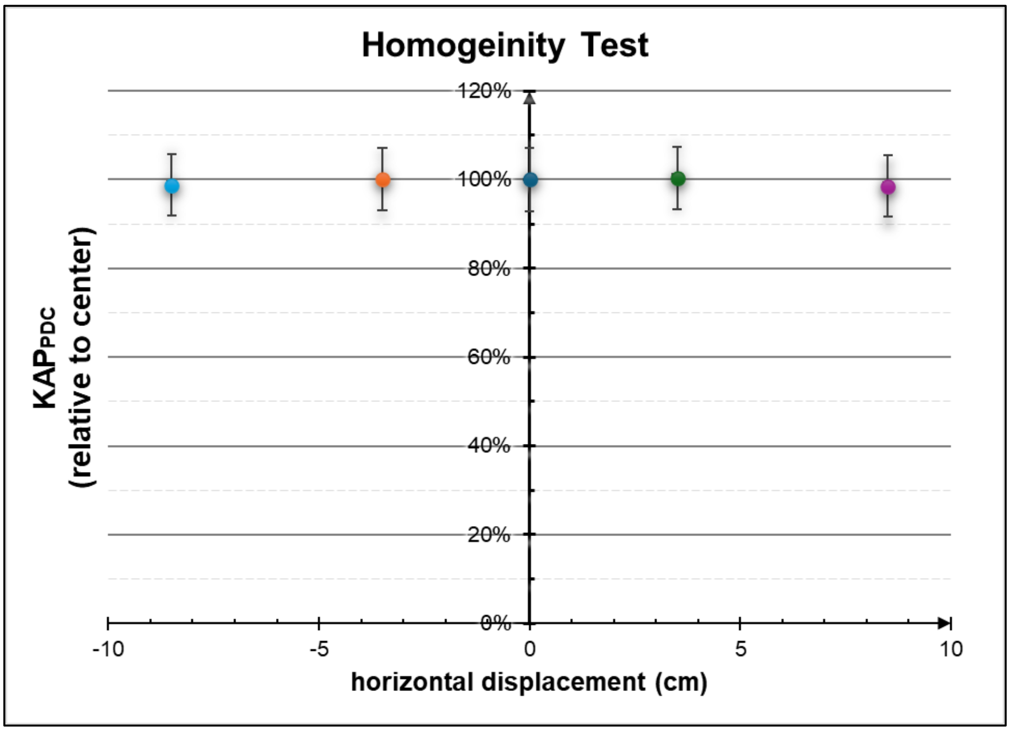
The second test implemented was the **Reproducibility Test**, in which, KAP values were compared for PDC against the ionization chamber, which was at the same position with the same X-ray field aperture.

A third test is still in progress that is the **Long-term Stability Tests**, by which, as the central position of PDC is chosen, 10 measurements were taken, and the average values were compared with the reference ones. As this last test is on demand, these results are no longer available for this work.

4. RESULTS

Figure 5 shows the results of the homogeneity test, for the KAP at different horizontal displacements, with PDC and KAP meter (after PDC calibration). Each point, in each position, is the average of the KAP for all IEC X-ray qualities, considering each radiation quality, the reason between the value for that radiation quality and the value of KAP at the central position (at the same energy).

Figure 5: Results for Homogeneity test (for PDC), corrected for temperature and pressure, at horizontal displacements with PDC.

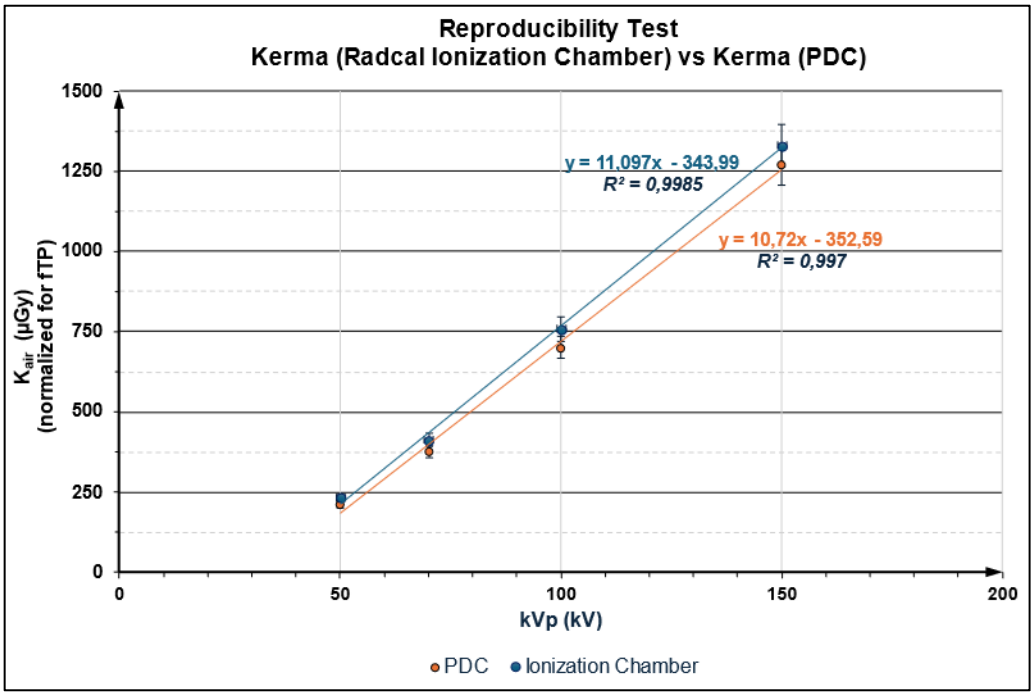


Source: Authors' results.

The uncertainties in KAP are considering the mean value of KAP, for each kVp, at the central position and at the displacement position. Considering the estimated uncertainties, the results in homogeneity tests are with variation below 3 %, given that all the displacements (from the center to the 3.5 cm, and for 8.5 cm position – to the left and to the right), and in KAP measure. The results are in accordance with IEC 60580:2019 [10], considering the PDC (Radcal®) as a reference meter.

A significant finding of this study is the reproducibility of measurements obtained using the PDC (Radcal®). Figure 4 illustrates the strong correlation in Kerma in air (µGy) values, measured by the PDC and a reference ionization chamber (Radcal®, model 10x5-180) across a range of kVp settings. As depicted in Figure 5, the PDC exhibited low variability (between 4 % and 9 %), in Kerma in air measurements, compared to the values measured with reference ionization chamber (Radcal®, model 10x5-180), demonstrating a good agreement within the margin of error for each kVp.

Figure 5: Homogeneity test (for PDC), corrected for temperature and pressure.



Source: Authors' results.

The long-term stability test is currently in progress and data collection is still underway.

5. CONCLUSIONS

The system demonstrated good reproducibility in Kerma measurements (± 2%), with reliable energy response and repeatability across all radiation qualities. During the calibration process, the PDC exhibited good reproducibility in measuring KAP, with values differing by ± 3% compared to those measured with the reference ionization chamber (Radcal®) [9], qualifying it as a reference meter for KAP according to IEC 60580 (2019) [10]. Additionally, the PDC displayed good performance in the homogeneity test, with variations within 2 % when positioned 3.5 cm to both sides and when positioned 8.5 cm, at both sides. In all tests, the PDC's response is within uncertainties, allowing it to be used as a reference instrument for calibrating clinical KAP equipment.

In the future, the PDC will be used to calibrate clinical meters used in interventional radiology procedures. For this purpose, the LCI system will be structured using the TOPAS Monte Carlo code simulation to evaluate the energy dependence of the PDC, compare the results with those of the KAP clinical meter, and with spectra characterized with CdTe spectrometer, to validate the method.

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CONFLICT OF INTEREST

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