Calibration of a pencil ionization chamber with and without preamplifier

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Abstract. The pencil ionization chamber is a cylindrical dosimeter developed for computed tomography beams. Many kinds of ionization chambers have a preamplifier connected to the chamber to make it electrically more stable, specially for field instruments. In this study, the performance of a Victoreen pencil ionization chamber with the original preamplifier and after its removal was compared. The objective of the preamplifier removal was to enable connecting the chamber to other kinds of electrometers available in the laboratory. To assure the proper performance of the chamber in its new condition, the main quality control tests were performed, as short and long term stability, leakage current and energy dependence in diagnostic and mammography calibration beams. The behavior of the pencil ionization chamber before and after the removal of the preamplifier was very similar, and the results obtained were always within the limits of international recommendations. The results obtained in both situations allow, if necessary, the preamplifier removal of the system without lack of precision in the measurements.

1. Introduction

The pencil ionization chamber was developed for computed tomography (CT) dosimetric purposes, and since its introduction it has been very often used. The pencil ionization chamber allows the determination of the computed tomography dose index (CTDI), the most common dose quantity in CT dosimetry [1-5].

Many kinds of ionization chambers were manufactured with a signal digitizing preamplifier, that guarantees a better electrical stability, and it is useful specially for field instruments. However, in most cases, the preamplifier can only be coupled to a specific electrometer. Nevertheless, for laboratory instruments it may be interesting to remove the preamplifier to earn more versatility.

The aim of this study was to evaluate the performance of a Victoreen pencil ionization chamber with the original preamplifier and after its removal. This pencil ionization chamber could have been bought without its preamplifier from the manufacturer, but at that time it did not seem to be necessary. Only recently this need appeared, and a laboratory adaptation was made removing the preamplifier and using a triaxial connector to enable the use of the chamber with other kinds of electrometers available in the laboratory.

The main quality control tests, as short and long term stability, leakage current and energy dependence in diagnostic and mammography calibration beams, were performed to verify the performance of the chamber with and without the preamplifier. The study was realized using the available radiation beams at the laboratory.

2. Materials and Methods

A Victoreen pencil ionization chamber, model 660-6, was tested coupled to a Victoreen electrometer, model 660, when using its original preamplifier, and coupled to a PTW electrometer, model UNIDOS 10001, after the preamplifier removal. The chamber presents a sensitive volume of 3.2 cm³, a sensitive length of 10 cm, and it is not sealed. The measures of this chamber are proportional to the irradiated length.

A $^{90}Sr + ^{90}Y$ check source, *Physikalisch-Technische Werkstätten* (PTW; 5.77 MBq, 2003), was used to perform the repeatability and reproducibility tests. For most types of ionization chambers, supports for repeatability and reproducibility tests are commercially available. However, this is not the case of supports for pencil ionization chambers. Therefore, a homemade acrylic support was utilized for those two tests [6].

It was not possible to measure the leakage current before the preamplifier removal, because of its manual zero adjustment. After the removal, the leakage current was measured before and after irradiation with the PTW check source.

Two X-ray systems were used for the energy dependence test. The first one was a diagnostic radiology level equipment, *Medicor Mövek Röntgengyara*, model *Neo-Diagnomax*, that operates from 40 to 125 kV at the radiographic mode, and from 45 to 100 kV at the fluoroscopic mode. Diagnostic qualities defined by the *International Electrotechnical Commission*, IEC 61267 [7], were used in this system, and their parameters are listed in Table I. The reference system for these qualities was a parallel plate ionization chamber with 1 cm³ of sensitive volume, PTW, model 77334, with a PTW electrometer, model UNIDOS 10001. This chamber was calibrated by PTW, with traceability to the German Primary Standard Dosimetry Laboratory, *Physikalisch-Technische Bundesanstalt* (PTB).

Table I. IEC diagnostic radiology qualities in the *Medicor Mövek Röntgengyara* X-ray equipment.

Radiation Quality	Voltage (kV)	Total Filtration (mmAl)	Half-Value Layer (mmAl)	Effective Energy (keV)
		Direct Beams		
RQR3	52	2.5	1.82	32.0
RQR5	70	2.5	2.45	39.2
RQR7	90	2.5	3.10	46.0
		Attenuated Beams		
RQA3	52	12.5	4.0	38.8
RQA4	63	18.5	5.7	45.6
RQA5	70	23.5	7.1	51.8
RQA6	80	29.5	8.4	57.9
RQA7	90	32.5	9.1	62.9

The second X-rays system was a low energy system *Rigaku Denki Co. Ltd.* Generator, type *Geigerflex,* and a *Phillips* tube, model PW 2184/00. This equipment operates from 20 to 60 kV. Mammography qualities similar to those from the *National Institute of Standards and Technology* (NIST), defined by the *International Atomic Energy Agency* (IAEA) [8] were used in this system. In Table II the parameters of these qualities are listed. The reference system utilized in this case was a parallel plate ionization chamber *Radcal Corporation*, model 10x5-6M, with a *Radcal Corporation* electrometer, model 9015; its sensitive volume was 6 cm³. This chamber has a calibration certificate from the *Center for Devices and Radiological Health*, *Food and Drug Administration*, USA, and its calibration is traceable to NIST.

Table II. Mammography qualities in the *Rigaku Denki* X-ray equipment.

Radiation Quality	Voltage (kV)	Half-Value Layer (mmAl)	Effective Energy (keV)
Direct Beams (Total Filtration: 0.06 mmMo)			
RXM20	20	0.28	13.6
RXM23	22.5	0.32	14.8
RXM25	25	0.33	15.1
RXM28	27.5	0.34	15.3
RXM30	30	0.35	15.6
RXM32	32.5	0.37	16.0
RXM35	35	0.38	16.2
Attenuated Beams (Total Filtration: 0.06 mmMo + 2mmAl)			
RXM20x	20	0.52	18.5
RXM23x	22.5	0.56	18.7
RXM25x	25	0.58	18.8
RXM28x	27.5	0.61	19.0
RXM30x	30	0.67	19.5
RXM32x	32.5	0.72	19.7
RXM35x	35	0.85	21.6

3. Results and Discussion

The repeatability test was performed by taking several measurements with the chamber exposed to the check source under reproducible conditions. According to international recommendations [9], the maximum acceptable coefficient of variation is 1% for CT specific chambers. The highest coefficient of variation obtained was 0.32%, before the preamplifier removal, and 0.22%, after the preamplifier removal, that are values within the limit.

The reproducibility test was obtained by plotting the results of the repeatability test, before and after the preamplifier removal, in function of time, so the ionization chamber long-term stability could be observed for both conditions. As stated by the norm IEC 61674 [9], the medium value obtained in each repeatability test must not differ from the reference value more than 3%. FIG. 1 and 2 show the results obtained for the pencil ionization chamber. All values obtained in this work were within the recommended limit.

The leakage current was measured during 20 minutes, before and after irradiation, and the maximum leakage current obtained was 0.34% of the measurement obtained in the repeatability test. According to the norm IEC 61674 [9], the leakage current of a dosimeter shall not exceed 5% of the minimum effective air kerma rate of the range in use for at least 1 minute. The maximum leakage current obtained before irradiation represented only 1.4% of the ionization current produced by the minimum air kerma rate used in this study (0.534mGy/min).

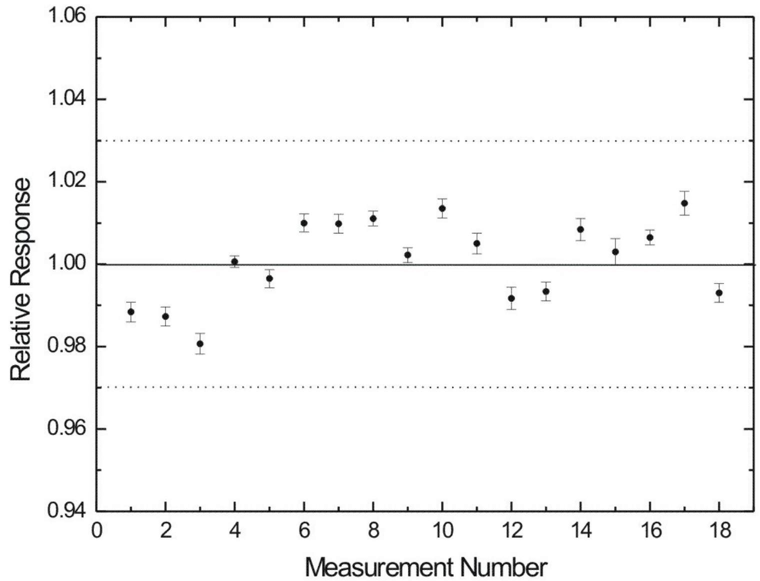

FIG. 1. *Reproducibility test of the Victoreen pencil ionization chamber, with the preamplifier, using a* $^{90}Sr + ^{90}Y$ *check source.*

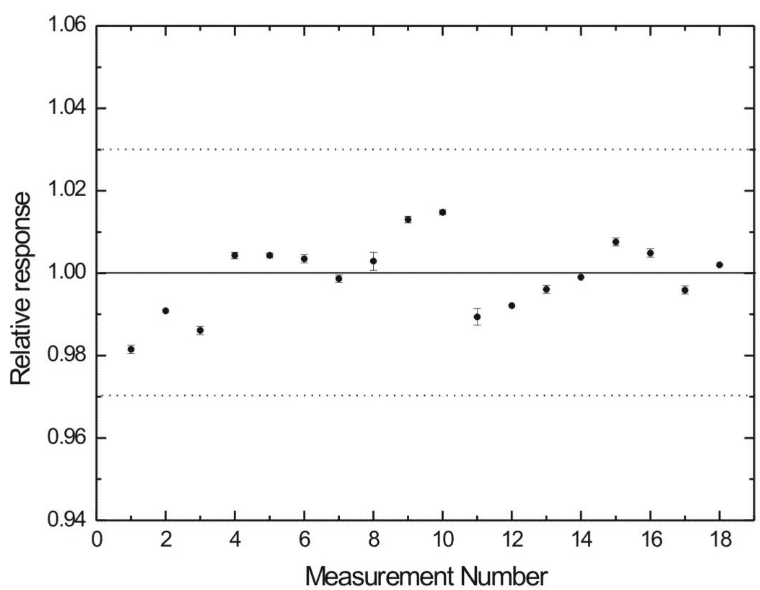

FIG. 2. *Reproducibility test of the Victoreen pencil ionization chamber, without the preamplifier, using a* $^{90}Sr + ^{90}Y$ *check source.*

For the energy dependence test, the chamber was calibrated in the beam qualities described in Tables I and II. The calibration coefficients [10] obtained are showed in Tables III and IV. The energy dependence (difference between the highest and the lowest calibration coefficients in percentage) of the pencil ionization chamber for those qualities is showed in Table V for both cases (with and without the use of preamplifier). FIG. 3, 4, 5 and 6 show the energy dependence curves of the chamber in those qualities. The values were normalized for the highest energy qualities. The results were similar in most of the cases for the condition of use and without use of the preamplifier, but for the attenuated diagnostic beams the lowest energy dependence was obtained after the preamplifier removal. Probably these results are consequence of the interference of the manual zero adjustment of the preamplifier in the measures that were close to the inferior display limit of the electrometer.

Table III. Calibration coefficients for a Victoreen pencil ionization chamber in IEC diagnostic radiology standard beams, with and without the use of its original preamplifier.

Radiation Quality	Calibration Coefficients	
	With Preamplifier (Dimensionless)	Without Preamplifier (x 10^8 Gy/C)
RQR3	1.04 ± 0.05	1.03 ± 0.05
RQR5	1.06 ± 0.06	1.02 ± 0.05
RQR7	1.05 ± 0.05	1.04 ± 0.06
RQA3	1.03 ± 0.07	1.08 ± 0.06
RQA4	1.15 ± 0.06	1.11 ± 0.06
RQA5	1.20 ± 0.07	1.10 ± 0.06
RQA6	1.19 ± 0.06	1.11 ± 0.06
RQA7	1.20 ± 0.06	1.12 ± 0.06

Table IV. Calibration coefficients for a Victoreen pencil ionization chamber in mammography standard beams, with and without the use of its original preamplifier.

Radiation Quality	Calibration Coefficients	
	With Preamplifier (Dimensionless)	Without Preamplifier (x 10^8 Gy/C)
RXM20	1.054 ± 0.036	1.060 ± 0.035
RXM23	1.039 ± 0.034	1.048 ± 0.035
RXM25	1.027 ± 0.034	1.044 ± 0.035
RXM28	1.025 ± 0.034	1.040 ± 0.034
RXM30	1.022 ± 0.034	1.037 ± 0.034
RXM32	1.017 ± 0.033	1.031 ± 0.034
RXM35	1.009 ± 0.033	1.027 ± 0.034
RXM20x	0.991 ± 0.038	1.013 ± 0.036
RXM23x	0.996 ± 0.040	1.010 ± 0.035
RXM25x	0.992 ± 0.034	1.006 ± 0.035
RXM28x	1.000 ± 0.034	1.008 ± 0.035
RXM30x	1.001 ± 0.035	1.010 ± 0.035
RXM32x	1.004 ± 0.034	1.014 ± 0.035
RXM35x	1.012 ±0.034	1.023 ± 0.038

Table V. Energy dependence of the pencil ionization chamber for several radiation qualities.

Radiation Quality	Energy Dependence	
	With Preamplifier (%)	Without Preamplifier (%)
IEC diagnostic radiology qualities Direct beams	1.9	2.0
IEC diagnostic radiology qualities Attenuated beams	16.5	3.7
Mammography qualities Direct beams	4.5	3.2
Mammography qualities Attenuated beams	2.1	1.7

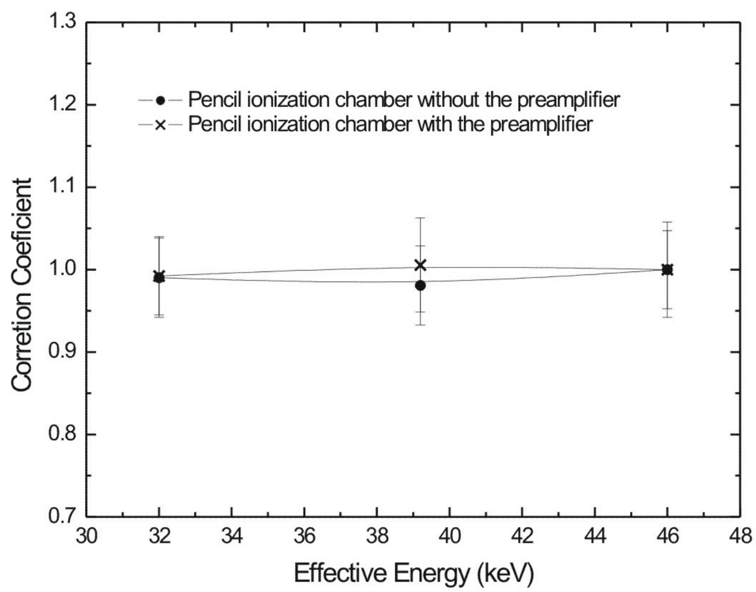

FIG. 3. *Energy dependence curve for the Victoreen pencil ionization chamber, before and after the preamplifier removal, in IEC diagnostic radiology qualities, direct beams. The calibration coefficients were normalized for the highest energy quality (46.0 keV).*

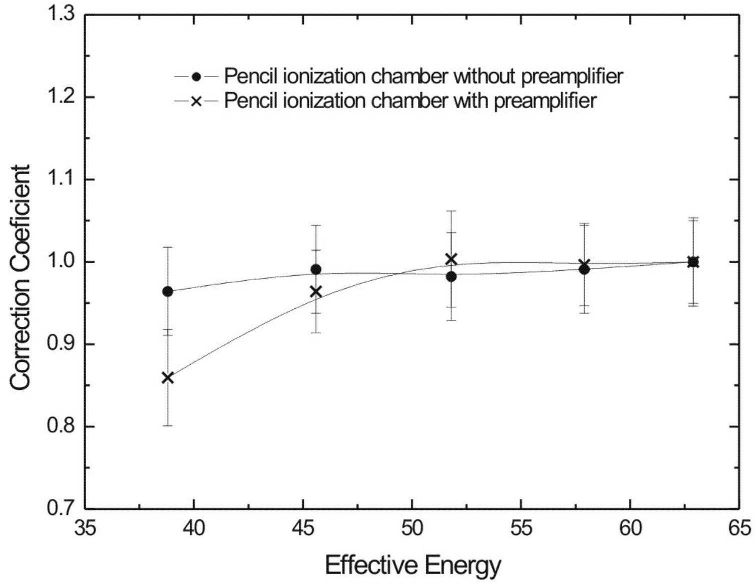

FIG. 4. *Energy dependence curve for the Victoreen pencil ionization chamber, before and after the preamplifier removal, in IEC diagnostic radiology qualities, attenuated beams. The calibration coefficients were normalized for the highest energy quality (62.9 keV).*

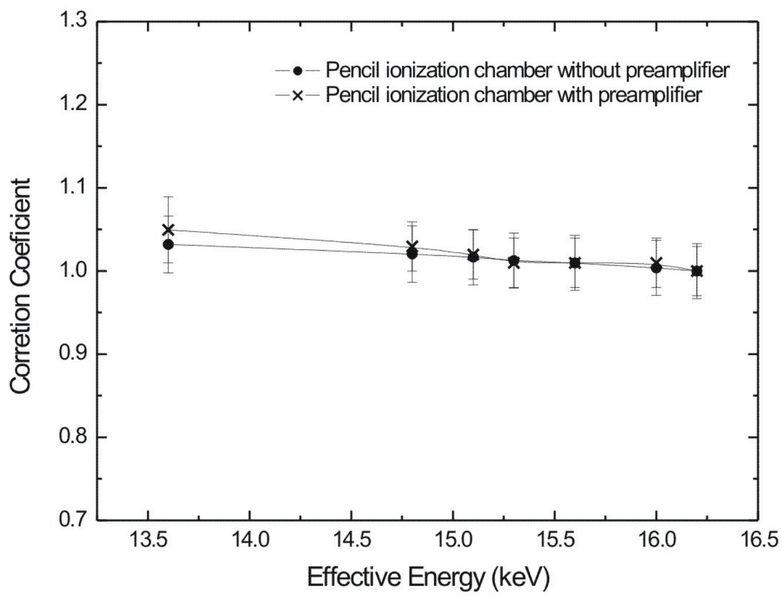

FIG. 5. *Energy dependence curve for the Victoreen pencil ionization chamber, before and after the preamplifier removal, in mammography qualities, direct beams. The calibration coefficients were normalized for the highest energy quality (16.2 keV).*

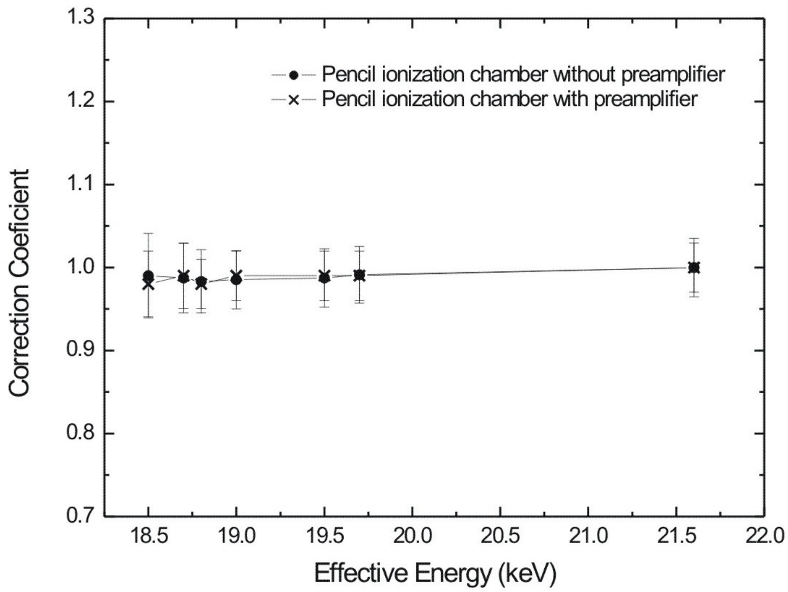

FIG. 6. *Energy dependence curve for the Victoreen pencil ionization chamber, before and after the preamplifier removal, in mammography qualities, attenuated beams. The calibration coefficients were normalized for the highest energy quality (21.6 keV).*

The performance of the pencil ionization chamber with and without the preamplifier was similar and satisfactory, except when the air kerma rates were close to the inferior display limit of the electrometer used before the preamplifier removal.

4. Conclusions

This study shows that it is possible to easily adapt a pencil ionization chamber, originally with a preamplifier, to be used with other kinds of electrometers than its original Victoreen electrometer. The results obtained before and after the preamplifier removal were similar in behavior, showing that the adaptation did not imply in lose if precision in the measurements.

5. Acknowledgements

The authors wish to acknowledge the partial financial support of Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil.

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