Original Article

CALIBRATION OF IONIZATION CHAMBERS FOR COMPUTED TOMOGRAPHY BEAMS IN BRAZIL: THE PRESENT REALITY*

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Abstract

OBJECTIVE: The aim of this study was to establish a calibration methodology specific for pencil ionization chambers used in computed tomography dosimetric procedures, in compliance with the most recent recommendations. The study was developed at the Calibration Laboratory of the Instituto de Pesquisas Energéticas e Nucleares. MATERIALS E METHODS: An industrial X-ray equipment, several types of ionization chambers, a mobile collimator (diaphragm type), and several high purity aluminum filters were utilized in this study. RESULTS: Diagnostic radiology standard irradiation fields were established according to IEC 61267 standard, and an adequate calibration procedure for pencil ionization chambers was elaborated. CONCLUSION: The appropriate calibration of pencil ionization chambers is already a reality in Brazil. The calibration procedure was defined on the basis of international standards and on a comparative study using two different methodologies.

Keywords: Pencil ionization chamber; Calibration methodologies; Standard beams.

INTRODUCTION

No doubt, the invention of computed tomography (CT) has been a significant milestone in medicine in the twentieth century so much that its inventors, Godfrey Hounsfield and Alan Cormack, were awarded with the Nobel Prize in Medicine. The CT basic principle is based on the possibility to produce images of a two- or three-dimensional object by means of multiple projections of this object. The image is formed by a set of projections of a region of the body. The projections are acquired through several irradiations on the region, at different angles, by a collimated beam, the transmitted radiation being measured by a detector. The detector measurements are processed by a computer that reconstructs the image.

Although the CT diagnostic potential is unquestionable, great care should be taken because of ionizing radiation and considering that nearly always doses are higher than doses applied in conventional radiological procedures[(1)]. Surveys have been showing a huge increase in the number of computed tomography devices in use. In the United Kingdom, studies have shown that although CT procedures represent only 7% of the total number of medical procedures utilizing X-radiation, they account for about 47% of the total collective dose[(2)].

For determining the absorbed dose in an environment exposed to ionizing radiation an appropriate device called dosimeter is utilized. Among several types of dosimeters, there are those based on a gas ionization measurement like the ionization chambers[(3–6)].

The ionization chamber utilized for CT dosimetry is a non-sealed cylindrical chamber with sensitive length between 10 and 15 cm, called pencil ionization chamber. One typical characteristic of this chamber is its uniform response to incident radiations in every angle around its axis. Therefore, it is appropriate for utilization in equipment where the X-ray tube rotates like in CT.

Usually the reading by this type of chamber is expressed in dose or exposure units x length (mGy.cm or R.cm), so as to provide the computed tomography dose index (CTDI), that is the principal dosimetric quantity used in CT [(7–11)].

Measures provided by radiation detectors are not absolute representations of reality. An estimation of actual values demands the instrument calibration. The instrument calibration allows the user to check its correct operation and provides a calibration coefficient for estimation of a real value. The calibration coefficient expresses the quotient between the conventional real value and the value displayed by the instrument to be calibrated corrected to the reference environmental conditions. Instruments require periodical recalibrations because their characteristics vary along time[(12,13)].

The implementation of a specific calibration procedure for pencil ionization chambers is a very recent practice and this service is available from few laboratories worldwide. An example is that only in 2005 the International Atomic Energy Agency (IAEA), considering the increasing application of CT for medical diagnosis purposes, recommended that their calibration laboratory was qualified to offer the service of pencil ionization chambers calibration up to 2006–2007[(14)].

The Laboratory of Instruments Calibration (Laboratório de Calibração de Instrumentos – LCI) of the Institute of Energetic and Nuclear Researches (Instituto de Pesquisas Energéticas e Nucleares – IPEN) has been seeking to update its calibration services, taking into consideration the users needs and the latest international recommendations, besides being aware of new procedures and future trends in this field. Therefore, this study had the objective of supporting the implementation in the LCI of a new service still rare in calibration laboratories worldwide and inexistent in Brazil (none of the calibration laboratories authorized by the National Commission of Nuclear Energy (Comissão Nacional de Energia Nuclear – CNEN) offers calibration service for CT-specific ionization chamber). It is important to note, however, that a demand for this calibration service already exists in Brazil, and it should increase in the future, considering that the number of CT equipment and procedures is increasing in the country.

MATERIALS AND METHODS

A Pantak/Seifert Isovolt 160HS model industrial X-ray equipment owned by LCI-IPEN, was utilized for determining standard radiation fields for CT as well as other fields for conventional radiodiagnosis. This is a high-frequency equipment with inherent 0.8 mmBe filtration. Voltage interval is 5 to 160 kV and current interval is 0.1 to 45 mA. The standard system for these beams is a Physikalisch-Technische Werkstätten (PTW) 77334 model parallel plate ionization chamber with sensitive volume of 1 cm^3, and a PTW Unidos 10001 electrometer. This chamber is a secondary standard certified by Physikalisch-Technische Bundesanstalt (PTB), Germany.

A PTW 34014 model monitor chamber coupled with a PTW Unidos E 10010 model electrometer was utilized during all the measurements aiming at establishing the X-radiation intensity constancy.

The X-radiation system has a laser positioning system that defines precisely the field center and the focus-chamber distance allowing a simple and accurate detectors alignment.

The additional aluminum filters necessary for definition of standard radiation fields were manufactured from a same high-purity aluminum (> 99,999%) billet, by means of wire electroerosion. The Al filters utilized in tests for determining half-value layers (HVL) were 99.9% pure or better.

The ionization chamber utilized for determining HVLs was a PTW 31003A model thimble-type ionization chamber with sensitive volume of 0.3 cm^3. This chamber has been utilized for measuring HVL due its low energy dependence over a broad energy interval.

A 5.1 cm diameter collimator positioned at 37.8 cm from the tube focus was employed to determining standard radiation fields. The standard radiation field obtained at 1 m from the tube focus has 12.4 cm in diameter presenting vertical homogeneity > 97% and horizontal homogeneity > 94%.

An additional diaphragm collimator was employed to permit partial irradiations by pencil ionization chambers. This type of collimator is constituted by four 7 cm width lead plates mounted for displacement in pairs, permitting the obtainment of rectangular fields of several sizes.

RESULTS AND DISCUSSION

Table 1 shows the conventional radiology diagnosis beams characteristics in compliance with Standard IEC 61267[(15)]. All these standard radiation fields have been established in LCI-IPEN. The qualities recommended for CT chambers calibration are the RQR9 e RQA9 qualities[(16)]. Other qualities will be utilized for calibration of other dosimeters used in diagnostic radiology and also for a broader study on the pencil ionization chambers energy dependence.

Table 2 includes values obtained for first and second HVL, homogeneity coefficient (1st. HVL/2nd. HVL) and air kerma rates in each radiation quality. Air kerma rates in each quality were determined with a secondary Standard PTW 77334 chamber. Based on the HVL values the beams effective energy values were determined[17].

Comparing the HVL obtained in LC-IPEN with those included in Table 1, it is possible to observe several discordances between qualities. Presently this Standard is being reviewed and, considering that some HVL values are discordant, probably the new version will bring new HVL values. Considering that the LCI secondary standard system for these radiation qualities is certified by the PTB, Germany primary laboratory, we have decided to follow the methodology hitherto adopted in this laboratory: utilize the IEC 61267 voltage and added filtration parameters[15], without any adjustment, in an attempt to approach the HVL values established by this Standard. Notwithstanding, correction factors were applied to calibration coefficients of the secondary standard system for correcting HVL differences between LCI and PTB beams. It is important to observe that the HVLs reported by the PTB calibration certificate also do not present a complete concordance with Standard values.

There are some calibration methods for pencil ionization chambers and main difference among them is the irradiated portion of the chamber sensitive length. Following the establishment of standard radiation fields, two calibration methodologies were tested: with total irradiation of the chamber sensitive length – the most usual calibration method for dosimeters in general; and with partial irradiation of the chamber sensitive length, as recommended by the Standard IEC 61674[16]. Only two radiation qualities recommended for pencil ionization chambers calibration were utilized in these tests: RQR9 e RQA9.

In the majority of calibration procedures, the whole dosimeters sensitive area is irradiated. Also, it is possible to calibrate pencil ionization chambers in this way. Four pencil ionization chambers described in Table 3 were calibrated by this method, utilizing the established radiodiagnosis standard radiation fields. The chambers were positioned perpendicular to the anode-cathode axis to avoid the anodic effect. The resulting calibration coefficients are shown in Table 4.

The second methodology adopted in the present study has been described by Bochud *et al.*[18]. In their study, the researchers have concluded that results are better when 50% of the pencil ionization chamber sensitive volume is irradiated during calibration. This is also the Standard IEC 61647 recommendation[16]. The calibration procedure suggested by the present study is similar to the methodology with complete irradiation of the volume, with an additional collimation system allowing the partial irradiation of the chamber under calibration.

For ensuring an accurate collimation, the collimation system must be positioned the nearest possible to the chamber under calibration. This proximity, however, creates an undesirable effect: an increase in scattered radiation contribution in the reading. This effect is still more accentuated since the sensitive volume portion protected from the primary beam is not insensitive to the scattered radiation. For determining the calibration coefficient, the introduction of a correction factor for this effect is necessary. This correction is performed by determining a "residual reading" in the ionization chamber that is a reading related to a null radiation field. This residual reading can be estimated by means of a linear adjustment in measurements performed for at least three different radiation field sizes.

The four pencil ionization chambers described in Table 3 were calibrated according to this second methodology. The resulting calibration coefficients also are included in Table 4. During these calibration procedures, the movable collimation system was positioned at 6 mm from the chambers under calibration which also were positioned perpendicular to the anode-cathode axis. The horizontal opening of the field was fixed in 1.5 cm and the vertical opening ranged for allowing different sensitive lengths irradiation.

Comparing the two methodologies results, one can observe that percent differences between calibration coefficients obtained for RQR9 and RQA9 fields are 1.7%–4.6%. Bochud *et al.*[18] also have found deviations about 3.5% between calibration coefficients obtained through different methodologies. The differences in calibration coefficients are resulting from absence of response homogeneity along the chamber sensitive length, since in this type of ionization chamber there is always a sensitiveness reduction in sensitive length ends.

Both coefficients from pencil ionization chamber sensitive volume total irradiation and partial irradiation are correct. The difference is in what they express. When the chamber is completely irradiated, an intermediate calibration coefficient is obtained as if the decrease in sensitiveness in the extremity of the chamber was evenly distributed along the sensitive length. If in the dosimetry practice the whole volume of the chamber was evenly irradiated, this coefficient would be the most appropriate one. However, the majority of measurements are performed by means of slices at maximum 1–2 cm thick, centered in the pencil ionization chamber. So the ends of the chamber are much less exposed to radiation than its central region. Thus it is more recommended to avoid a total irradiation of the chamber sensitive volume during calibration process aiming at obtaining a calibration coefficient more compatible with the characteristics of the central region of the chamber.

The combined standard uncertainties involved in all calibrations performed during this project have been estimated according recommendations included in "Guia para a expressão da incerteza de medição" (Guidance on expression of uncertainty in measurement), of Associação Brasileira de Normas Técnicas (ABNT) (Brazilian Association of Technical Standards)[19,20], considering the uncertainties involved in all parameter considered as relevant in the measurement process. A 95% confidence interval (coverage factor (k) = 2) was considered.

CONCLUSION

The LCI is already qualified to deliver an adequate service for CT ionization chambers calibration in Brazil. Two calibration methodologies have been tested and compared and a calibration procedure has been elaborated applying the methodology considered as the most appropriate, with irradiation of 50% of the sensitive volume of a pencil ionization chamber. As a result, the LCI has complied in advance with the international recommendations from IAEA that only in 2005 had defined the implementation of a calibration service for this type of chamber in its laboratory as a goal to be achieved in 2006-2007.

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CALIBRAÇÃO DAS CÂMARAS DE IONIZAÇÃO

Tabelas

Table 1 Radiodiagnosis qualities according to standard IEC 61267[15].

Radiation quality	Voltage (kV)	Total filtration (mmAl)	CSR (mmAl)	Radiation quality	Voltage (kV)	Total filtration (mmAl)	CSR (mmAl)
Direct beams				Attenuated beams			
RQR2	40	2.5	1.0	RQA2	40	6.5	2.4
RQR3	50	2.5	1.5	RQA3	50	12.5	4.0
RQR4	60	2.5	2.0	RQA4	60	18.5	5.7
RQR5	70	2.5	2.5	RQA5	70	23.5	7.1
RQR6	80	2.5	2.9	RQA6	80	28.5	8.4
RQR7	90	2.5	3.3	RQA7	90	32.5	9.1
RQR8	100	2.5	3.7	RQA8	100	36.5	9.9
RQR9	120	2.5	4.5	RQA9	120	42.5	11.5
RQR10	150	2.5	5.7	RQA10	150	47.5	12.8

CSR, half value layer.

Table 2 Characteristics of radiation beams established in LCI.

Radiation quality	First CSR (mmAl)	Second CSR (mmAl)	Homogeneity coefficient	Effective energy (keV)	Air kerma rate (mGy/min.)
RQR2	1.44	1.80	0.80	25.10	13.79
RQR3	1.79	2.38	0.75	27.15	24.06
RQR4	2.09	2.92	0.72	28.80	35.35
RQR5	2.35	3.42	0.69	30.15	47.17
RQR6	2.65	3.99	0.66	31.65	60.39
RQR7	2.95	4.62	0.64	33.05	74.51
RQR8	3.24	5.20	0.62	34.40	89.81
RQR9	3.84	6.31	0.61	37.05	121.80
RQR10	4.73	7.79	0.61	40.75	175.19
RQA2	2.22	2.50	0.89	29.50	5.39
RQA3	3.91	4.15	0.94	37.30	3.39
RQA4	5.34	5.83	0.92	43.25	3.03
RQA5	6.86	7.32	0.94	49.40	3.40
RQA6	8.13	8.54	0.95	54.75	3.99
RQA7	9.22	9.70	0.95	59.70	4.87
RQA8	10.09	10.73	0.94	63.95	5.76
RQA9	11.39	12.16	0.94	71.15	7.93
RQA10	13.02	13.79	0.94	82.10	13.28

CSR, half value layer.

Table 3 Technical information on pencil ionization chambers utilized in this study.

Technical information	Pencil ionization chamber			
	C1	C2	C3	C4
Trademark	Victoreen	Radcal	Radcal	Radcal
Model	660-6	10 × 5-3CT	10 × 5-3CT	10 × 5-3CT
Sensitive volume (cm^3)	3.2	3.0	3.0	3.0
Sensitive length (cm)	10	10	10	10
	Preamplifier			
Trademark	—	Radcal	Radcal	Radcal
Model	—	9060	9060	9060
	Electrometer			
Trademark	PTW	Radcal	Radcal	Radcal
Model	Unidos 10001	9015	9015	9015

Table 4 Calibration coefficients obtained for four pencil ionization chambers described in Table 3, in standard radiation fields RQR9 and RQA9, for two different calibration methodologies: with total irradiation and with partial (50%) irradiation of the chamber sensitive volume under calibration.

Radiation quality	Calibration coefficient			
	C1 ($\times 10^8$ Gy/C)	C2 (dimensionless)	C3 (dimensionless)	C4 (dimensionless)
Total irradiation of the chamber sensitive volume				
RQR9	1.022	10.15	10.31	10.00
RQA9	1.005	11.08	11.16	10.24
Standard combined uncertainty	1.18%	1.51%	1.74%	1.50%
Irradiação parcial (50%) do volume sensível				
RQR9	0.990	9.77	9.87	9.80
RQA9	0.968	10.59	10.82	10.07
Standard combined uncertainty	1.34%	1.65%	1.85%	1.64%