Establishment of the practical peak voltage for standard computed tomography radiation qualities at a Calibration Laboratory

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Abstract— At the Calibration Laboratory of IPEN/CNEN-SP (LCI) several radiation qualities were established, and they are in use for the calibration of radiation detectors for clinical and industrial uses. In order to follow international recommendations, a new quantity has been established at the LCI, the practical peak voltage (PPV). In this work, an analysis of this quantity was made for the computed tomography standard radiation qualities RQT8 and RQT9. The PPV and the mean and peak kilovoltage values were measured with a noninvasive Radcal Accu-kV Diagnostic Sensor^{TM}, model 40X12-W meter. In order to compare the results obtained for PPV a Physikalisch-Technische Werkstätten (PTW) meter, model Diavolt^{TM}, was also utilized. The tests were performed with an X-ray system Pantak/Seifert, tube model MXR-160/22 (constant potential). The measurements were taken varying the distance between the focal spot and the meters. The uncertainties attributed to the quantities of kV and PPV for a noninvasive method did not exceed 5%, and therefore they were within the IAEA recommendations. In the corresponding measurements, increasing the distance between the focal spot and the meter, the PPV and the kV values should be constant. The results were within the predictions, and the PPV and the kV values presented variations within international recommendations. This type of quality control procedure is very important to verify the good reliability of the X-ray system of LCI, because it is utilized for routine calibration of dosimeters.

Keywords: noninvasive kVp meter; computed tomography; practical peak voltage; kVp

1. INTRODUCTION

Computed tomography (CT) is a technique used mainly in diagnostic and treatment planning. In these procedures the CT enables the accurate visualization of tumors providing to physicians an excellent tool to treat the patients. Because of the fact that the CT technique allows excellent images to obtain a good diagnostic and treatment planning, it was extensively utilized in the last years. However, the dose levels from CT typically exceed those from conventional radiography, and therefore the use of this technique has received attention from the society. In order to ensure a secure level of radiation received by the patient, the radiation detectors need to be calibrated. The calibration procedures are undertaken in specific laboratories that present special conditions, such as standard beams dosimeters, and a good characterization of the X-ray system.

At the Calibration Laboratory of IPEN (LCI), several instruments are routinely calibrated using several types of radiations (beta, gamma, X). To guarantee the required accuracy in the calibration procedures, it is necessary to characterize the X-ray equipment. Therefore several parameters need to be known such as tube voltage, tube current, anode angle, and inherent and added filtrations. The most important parameter is the tube voltage, because it strongly influences the dose to patients and the exposure of the image receptor.

There are some definitions for the X-ray tube and generator voltages that are largely used, but unfortunately these quantities are ambiguous or have no relation to the properties of the radiological images. One of these parameters is the peak kilovoltage (kVp) (IAEA, 2007), for which there is no agreement upon the quantity to measure what is designed peak kilovoltage. According to Bushong (1997), as the voltage across the tube may fluctuate (ripple, stability, etc.), the peak kilovoltage (kVp) can be defined as the maximum voltage applied to an X-ray tube. It determines the kinetic energy of the electrons accelerated in the X-ray tube and the peak of the X-ray emission spectrum.

In order to define a measurable standard quantity for the X-ray tube voltage, the practical peak voltage (PPV) was proposed by Kramer and collaborators (Kramer *et al.*, 1998). The PPV presents some interesting characteristics: capability to define a reproducible physical method for voltage measurement; easiness in its measurement; clinical relevance and pertinence to technical aspects of the X-ray equipment (IAEA, 2007).

At the LCI the PPV quantity was introduced for a standard diagnostic radiology quality RQR5 (Lucena *et al.*, 2010; Vitor *et al.*, 2012). In the present work noninvasive meters were utilized for the measurement of the PPV and the peak kilovoltage (kVp) at the X-ray system of LCI in the established standard computed tomography radiation qualities (IEC, 2005).

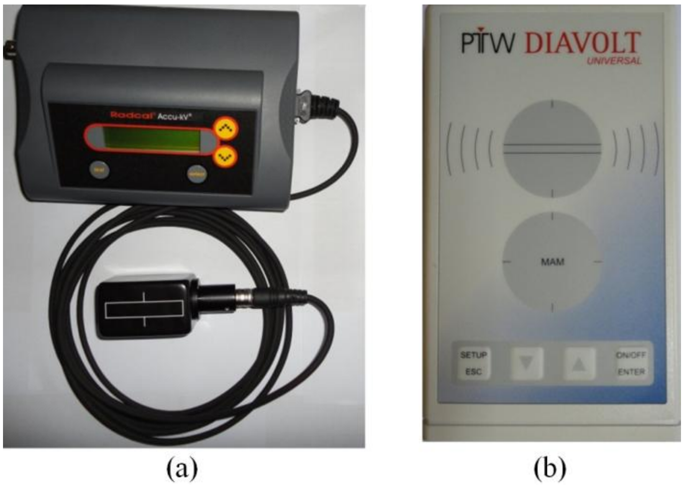
2. MATERIALS AND METHODS

The measurements of PPV and kVp were taken using a Pantak/Seifert X-ray system, model MXR-160/22 (constant potential) at LCI. The standard computed tomography radiation qualities used in this work are presented in Table 1. The reference system used to establish the standard computed tomography qualities was a RADCAL pencil ionization chamber, model RC3CT, with traceability to the German primary standard laboratory Physikalisch-Technische Bundesanstalt (PTB).

Table 1. Standard computed tomography radiation qualities at the Pantak/Seifert X-ray equipment, using a constant tube current of 10 mA

Radiation quality	Tube voltage (kV)	Additional filtration		Half-value layer (mmAl)	Air kerma rate (mGy/min)
		mmAl	mmCu		
RQT8	100	3.2	0.30	6.90	22.0 ± 0.33
RQT9	120	3.5	0.35	8.40	34.0 ± 0.51

The noninvasive meters used during the measurements were: a Radcal Accu-kV Diagnostic Sensor^{TM}, model 40X12-W meter, and a Physikalisch-Technische Werkstätten (PTW) meter, model Diavolt^{TM} (Figure 1).



(a) (b)

Figure 1. Photos of Radcal Accu-kV^{TM} (a) and PTW Diavolt^{TM} (b) noninvasive meters.

3. RESULTS AND DISCUSSION

For each standard computed tomography standard radiation quality (Table 1), the meters were positioned at the following distances: 0.37, 0.50 and 1.00 m from the focal spot of the X-ray tube. The number of measurements was obtained according to each detection system. The Accu-kV^{TM} acquisition software provides one measurement every 0.153 ms during 5s (approximately 32,000 measurements). The Diavolt^{TM} system acquisition was manual, and 10 measurements were taken for each distance. These data were used in order to obtain the mean values and their associated mean standard deviations.

The distance of 0.37 m is the minimum distance at which the setup may be mounted without the dissembling of the X-ray filtering wheel, collimating system and monitor ionization chamber. In order to take the measurements at the same setup used for the calibration procedures, the X-ray system was not dismounted.

For the RQT10 (150kV; 4.2mmAl+0.35mmCu of additional filtration) radiation quality the measurements could not be taken due to limitations of the meters which work below 150 kV.

3.1 PPV MEASUREMENTS

The PPV quantity was measured in function of distance, and the results obtained are shown in Tables 2 and 3. The maximum difference between the measurements obtained with the two kV meters was 3.0%, for a distance of 0.50 m and the RQT9 radiation quality.

Table 2. Mean values of the PPV, measured with the Accu-kV^{TM} and Diavolt^{TM} meters in RQT8 standard computed tomography standard radiation quality

	PPV (kV)		
Distance (m)	Accu-kV^{TM}	Diavolt^{TM}	Difference (%)
0.37	102.2±2.7	104.8±3.1	2.5
0.50	102.2±2.9	104.2±3.0	1.9
1.00	102.0±2.5	104.2±3.1	2.1

Table 3. Mean values of the PPV, measured with the Accu-kV^{TM} and Diavolt^{TM} meters in RQT9 standard computed tomography standard radiation quality

	PPV (kV)		
Distance (m)	Accu-kV^{TM}	Diavolt^{TM}	Difference (%)
0.37	122.1±3.0	118.9±3.4	2.7
0.50	122.0±3.2	118.5±3.2	3.0
1.00	121.8±3.0	118.6±3.3	2.7

All values, obtained with both meters, are within the international recommendations (IAEA, 2007) which establish a maximum variation of 5%. It is important to note that in this work the X-ray system characteristics were evaluated specific of LCI, and thus the purpose is not to address the advantages or limits of the two noninvasive meters utilized for the measurements.

The main reason for the higher variation of the PTW Diavolt^{TM} equipment is probably due to the difference between the setup configurations and the materials utilized for the additional filtration. The standard computed tomography radiation qualities established at LCI utilize both aluminum and copper filters while the Diavolt^{TM} equipment presents just aluminum filters on its software menu. In another study, Vivolo *et al.* (2012), using the standard diagnostic radiology radiation quality RQR5, presented results with a better agreement among the meters and the nominal applied voltages.

3.2 kV MEASUREMENTS

The peak and mean kV were measured with the Radcal Accu-kV™ as a function of distance, and the results are presented in Tables 4 and 5 for the kVp values and in Tables 6 and 7 for the mean kV values. Comparing the results obtained with the meters and the nominal applied voltages, the maximum difference obtained was 2.3% for the kVp and 2.2% for the mean kV.

Table 4. kVp values, measured with the Accu-kV™ noninvasive meter and the nominal applied voltage in RQT8 standard computed tomography radiation quality

	kVp (kV)		
Distance (m)	Accu-kV™	Nominal	Difference (%)
0.37	102.3±2.7	100.0	2.3
0.50	102.2±2.5	100.0	2.2
1.00	102.1±2.5	100.0	2.1

Table 5. kVp values, measured with the Accu-kV™ noninvasive meter and the nominal applied voltage in RQT9 standard computed tomography radiation quality

	kVp (kV)		
Distance (m)	Accu-kV™	Nominal	Difference (%)
0.37	122.2±2.9	120.0	1.8
0.50	122.2±2.7	120.0	1.8
1.00	122.0±2.5	120.0	1.7

Table 6. Mean kV values, measured with the Accu-kV™ noninvasive meter and the nominal applied voltage in RQT8 standard computed tomography radiation quality

	mean kV (kV)		
Distance (m)	Accu-kV™	Nominal	Difference (%)
0.37	102.2±2.5	100.0	2.2
0.50	102.2±2.4	100.0	2.1
1.00	101.9±2.5	100.0	1.9

Table 7. Mean kV values, measured with the Accu-kV™ noninvasive meter and the nominal applied voltage in RQT9 standard computed tomography radiation quality

	mean kV (kV)		
Distance (m)	Accu-kV™	Nominal	Difference (%)
0.37	122.1±2.8	120.0	1.7
0.50	122.1±2.7	120.0	1.7
1.00	121.8±2.6	120.0	1.5

According to Tables 4, 5, 6 and 7, it is possible to verify that the mean and peak kV values are very close. This was expected for constant potential systems, where the voltage applied to the X-ray tube usually does not change during the exposure (X-ray beam power on). Otherwise, if the value of the kVp quantity is increased, the kinetic energy of the electrons that reach the target (anode) increases, and the mean energy of the X-ray spectrum will be increased too (Bushong, 1997).

4. CONCLUSIONS

An evaluation of the noninvasive measurement of the PPV and kVp in the standard computed tomography radiation qualities is presented in this work. These measurements are part of the quality control program of the X-ray systems at LCI, with the main purpose to ensure reliable calibrations. The advantage of the noninvasive meters is related to the fact that they are precise and of easy handling. All results were considered satisfactory and in good agreement with the recommended limits. At the calibration distance (1.0 m), the maximum difference between the PPV values obtained using the two meters was 2.7% (RQT9). The maximum differences between the nominal voltage and kVp measurements were 2.3% for the peak kVp and 2.2% for the mean kV, showing good agreement between the meter and the applied tube voltage.

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