

X-RAY BEAM QUALITIES FOR DENTAL RADIOLOGY PURPOSES

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ABSTRACT

In order to establish characteristics or properties of equipment for diagnostic radiology, e.g. ion chambers and semiconductor detectors, calibration laboratories offer a set of well-defined radiation conditions, called X-ray qualities, which can be used for many Physics studies and medical purposes. The standardization of radiation qualities has been carried out in several fields of study, but little attention has been given to the area of dental radiology, mainly for medical and physical applications using single-phase units with half-wave rectification. For this reason, a single-phase dental unit with adjustable peak voltage and tube current, called “variable potential X-ray equipment”, was developed aiming to define X-ray beam qualities for test and calibrations purposes. X-ray spectra at 50, 60 and 70 kVp were determined by using a CdTe detector and compared with those obtained for ten commercial X-ray dental units. As a result of this study, a set of X-ray qualities for the variable potential X-ray equipment was determined. The X-ray qualities spectra were utilized as reference for determination of a new set of X-ray qualities characterized for a constant potential X-ray equipment. Thus, sets of X-ray qualities were standardized and implemented in two X-ray laboratories: one with the variable potential X-ray equipment and other with constant potential X-ray equipment. These reference X-ray beam qualities should be used for test and calibration purposes involving scientific studies and services.

1. INTRODUCTION

The medical use of ionizing radiation contributes significantly to the radiation exposure of individuals and populations. The interest in dental radiology is therefore very high due to the large amount of X-ray dental units and the large number of persons involved in taking radiographs [1]. In Brazil there are approximately 75,000 intra-oral dental X-ray units with 50 to 70 kVp tube potentials, according to the UNSCEAR Report 2000 [2]. The great majority of them are single-phase dental X-ray units and the examinations with these X-ray equipments represent approximately 30% of the total radiological procedures with ionizing radiation derived from medical practices [2].

In order to guarantee the safe operation of these dental X-ray units, the Brazilian Health Regulatory Agency (ANVISA-MS) established some requirements for quality assurance in dental radiology [3] and researchers have conversely developed instrumentation for assessing the technical parameters that influence the radiation dose and image in these X-ray

units [4-6]. However, the devices should be tested in reference X-ray beam qualities for dental radiology purposes.

Calibration laboratories offer a set of well-defined radiation conditions, called X-ray qualities, which can be used for many Physics studies and medical purposes. These X-ray qualities can be determined in terms of: (a) X-ray beam mean energy; (b) spectral resolution, (c) 1st and 2nd Half-Value Layers (HVL), and (d) total filtration. The standardization of radiation qualities has been carried out in several ionizing radiation fields, but in the area of dental radiology these qualities are scarce, mainly for medical and physical applications using single-phase units with half-wave rectification.

For this reason, a single-phase dental unit with adjustable kVp and mA, called “variable potential X-ray equipment”, was developed at the Centro Regional de Ciências Nucleares (CRCN-NE/CNEN), aiming to define X-ray beam qualities for test and calibrations purposes. X-ray spectra at 50, 60 and 70 kVp were determined by using a CdTe semiconductor detector and they were compared with those obtained for ten commercial X-ray dental units. From this study, a set of X-ray qualities was determined.

The X-ray qualities spectra were utilized for determining a new set of X-ray qualities for a constant potential X-ray equipment. Changes in total filtration and potentials applied to the X-ray tube from the constant potential X-ray equipment were carried out, aiming to define similar spectra for both constant and variable potential X-ray equipments.

These X-ray beam qualities, implemented in two X-ray laboratories: one with the variable potential X-ray equipment and other with constant potential X-ray equipment, should be used for test and calibration purposes related to scientific studies and services. They represent the first approach in order to establish Reference X-ray Qualities for dental radiology in Brazil.

2. MATERIAL AND METHODS

2.1. The X-ray Equipments

2.1.1. Variable potential X-ray equipment

The dental X-ray unit with adjustable kV and mA utilized in this study was a single-phase unit with half-wave rectification developed at the CRCN-NE. The nominal tube potential and current ranges are 20 to 80 kVp and 0.4 to 1 mA, respectively. A voltage divider (1/10000) was implemented for invasive waveform measurements. With this x-ray generator it is possible to have continuous X-ray production during a few minutes, thanks to the size of X-ray tube head, which provides suitable cooling (Fig. 1).

The aim of this unit was to define dental X-ray beam qualities which represent the photon mean energy found in commercial dental X-ray units. Thus, some quality control tests were performed in this unit, such as: half-value layers (HVL), radiation field size and uniformity, kVp measurements and radiation leakage through tube shielding, according to ANVISA quality criteria [3]. The inherent filtration was evaluated from the measurement of the 1st HVL at 60 kVp without additional filters [7].



Figure 1. The single-phase x-ray unit with adjustable kV and mA. X-ray tube assembly (left) and control panel (right).

2.1.2. Commercial dental X-ray equipments

Ten commercial dental X-ray units were utilized aiming to create a set of different X-ray spectra obtained at 50, 60 and 70 kVp. These X-ray spectra were compared with the spectra obtained in the variable potential X-ray equipment at the same tube potentials. Table 1 shows the characteristics of the commercial dental X-ray units. Measurements of HVL and kVp were also carried out.

Table 1. Main characteristics of the commercial dental X-ray units.

Dental X-ray unit	Nominal kVp	Nominal mA	Additional filtration (mmAl) *	Total filtration (mm Al) **
A	50	10	0.719±0.002	2.80
B	50	10	0.703±0.002	2.80
C	60	10	1.502±0.006	3.81
D	60	10	1.009±0.003	2.50
E	60	10	1.021±0.002	2.50
F	60	10	1.232±0.003	2.50
G	70	7	1.022±0.002	2.50
H	70	8	1.308±0.007	2.58
I	70	8	1.321±0.003	2.58
J	70	7	1.004±0.002	3.81

* Average value of five measurements

** Provided by manufacturer

2.1.3. Constant potential X-ray equipment

The constant potential X-ray unit utilized in this study was a Pantak HF320 with tungsten target and 3 mmBe window (inherent filtration). The nominal tube potential and current

ranges are 5 to 320 kVp and 1.0 to 30 mA, respectively. With this X-ray generator it is possible to have continuous X-ray production during hours, thanks to the cooling system.

The aim of this unit was to define dental X-ray beam qualities from those obtained for the variable potential X-ray unit. Changes in total filtration and potentials applied to the X-ray tube from the constant potential X-ray equipment were carried out, aiming to define similar spectra for both constant and variable X-ray equipments.

2.2. The X-ray Spectrometer

A CdTe Schottky diode detector (Amptek XR-100T CdTe) coupled to an amplifier and bias supply (Amptek PX2T-CdTe) was utilized to obtain the spectra at 50, 60 and 70 kVp for all X-rays units. The crystal size of this detector is $3 \times 3 \text{ mm}^2$ with 1 mm thickness. The nominal bias voltage was 400 V and the shaping time was 3 μs . The rise time discrimination (RTD) circuit was switched-on and the gain was set at 3.6. A Multichannel Analyzer (Amptek MCA-8000A) with up to 16k data channels was utilized for pulse analysis. The MCA was operated with 1024 data channels in this study. Spectra data were collected by means of an acquisition software (Amptek ADMCA).

The following experimental setup (Fig. 2) was utilized: (a) 3.5 m focus-detector distance (DFD); (b) 0.5 mA tube current; (c) additional filters utilized for both constant and variable X-ray equipment and the additional filters presented in Table 1 for the commercial X-ray units; and (d) two 2 mm thick tungsten pinholes with 0.4 mm and 1.0 mm collimator aperture diameters (Amptek EXVC). In order to reduce the x-ray beam field and, therefore, the scattered x-rays, an additional lead collimator with 15mm aperture diameter was positioned at half-distance between the focal spot and the detector (DFCol). Alignment was carried out by means of a laser beam and radiographic film images.

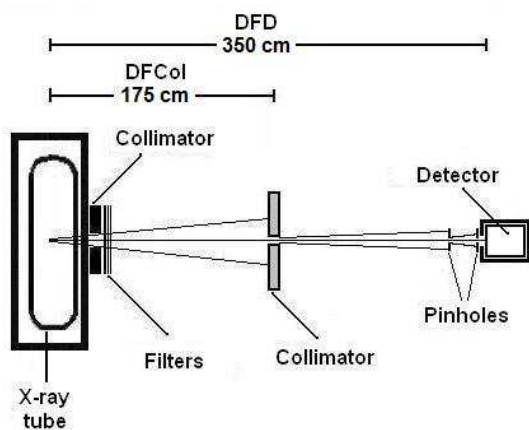


Figure 2. Experimental setup for x-ray spectrometry performed with the CdTe detector.

The commercial dental X-ray spectra obtained with this CdTe detector, without corrections, were compared with the ones from the variable potential X-ray unit at the same tube

potentials. After this step, the measured spectra from this X-ray unit were corrected by means of an unfolding procedure (stripping method) based on response functions obtained with Monte Carlo method [8]. Output corrected spectra were produced in 0.4 keV intervals for this CdTe detector.

The spectra from the variable potential X-ray unit were utilized to define similar spectra for the constant potential X-ray unit, mainly in relation to the X-ray beam mean energy.

2.3 The Radiation Meters

A Radcal ionization chamber, model 10X5-6, with 9060 converter and 9015 controller (electrometer) was utilized in order to perform the HVL measurements. The following experimental setup (Fig. 3) for these measurements was utilized: (a) 1.0 m focus-chamber distance (DFC); (b) 0.5 m focus-filter distance (DFP); (c) lead collimator with 20mm aperture diameter positioned in front of the X-ray tube window; (d) The additional filters utilized for both constant and variable X-ray equipment and the additional filters presented in Table 1 for the commercial X-ray units; (e) two lead collimators with 30mm aperture diameter positioned before and after the HVL filters.

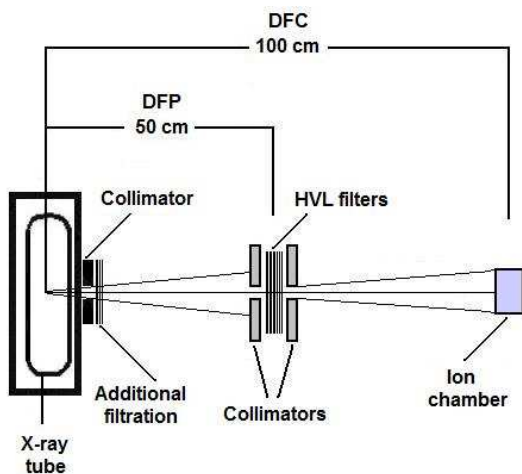


Figure 3. Experimental setup for HVL measurements.

A reference Radcal ionization chamber, model RC6, with 6517A Keithley electrometer was utilized in order to perform the air-kerma rate measurements. The following experimental setup was utilized: (a) 1.0 m focus-chamber distance (DFC); (b) lead collimator with 20mm aperture diameter positioned in front of the X-ray tube window; (c) The additional filters utilized for both constant and variable X-ray equipment.

A NE ionization chamber, model 2577C, coupled with NE electrometer, model Farmer 2670, was utilized for radiation field size and uniformity measurements for the reference X-ray unit. The measurements were evaluated along the horizontal and vertical axes with steps of 1 cm in a plane perpendicular to the radiation beam, at 1m DFC.

2.3 The kVp Meter

A Victoreen non-invasive X-ray test device, model 4000M+, was utilized for kVp measurements in all X-ray units. The meter was positioned on the table surface at 20 cm focus-meter surface distance. The results were compared with the X-ray spectrum energy endpoint obtained by means of the CdTe detector.

3. RESULTS AND DISCUSSION

3.1 Commercial Dental X-ray Units

kVp measurements were evaluated by means of the kVp meter and by X-ray spectrometry. The ANVISA doesn't establish an acceptable kVp value (it only establishes that the kVp should not be less than 50 kV, with tolerance of -3 kV). In relation to nominal kVp, the maximum deviation was 9.5%. According to quality control protocols, including ANVISA quality criteria, that value is considered acceptable. The kVp values measured with the kVp meter and the one estimated by spectrometry showed a good agreement. The maximum deviation among them was 9.1%.

X-ray attenuation curves were plotted in order to calculate the 1st and 2nd HVL for each dental X-ray unit (Fig. 4). The 1st and 2nd HVL ranged from 1.16 to 1.95 mmAl and from 1.44 to 2.45 mmAl, respectively. Although the total filtration and nominal kVp are different, it is observed that HVLs are close to each other, except for the X-ray units H, I and J.

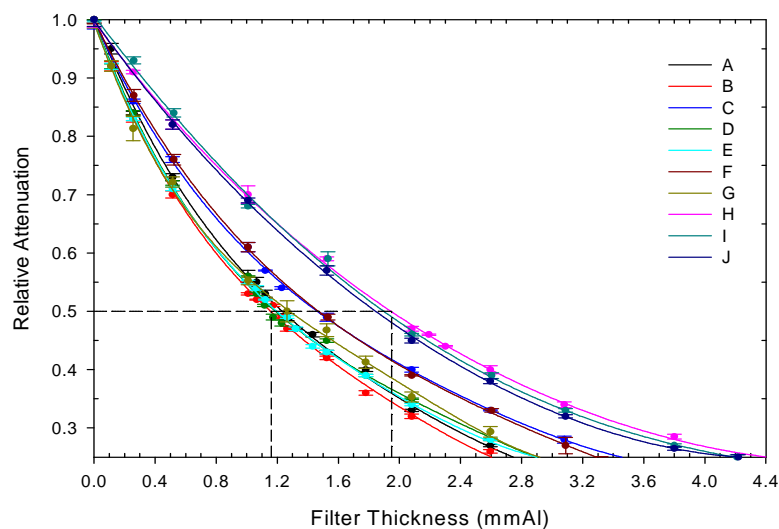


Figure 4. X-ray attenuation curves for determining the HVLs.

The X-ray spectrometry was performed with a CdTe detector for each X-ray unit. These spectra were grouped according to their nominal kVp. Therefore, each group was compared with the spectrum obtained from the variable potential X-ray unit at the same tube potential (Fig. 5 to 7).

3.2 Variable Potential X-ray Unit

The radiation field size and homogeneity were evaluated for this X-ray unit. The radiation field size was 16 cm diameter with 95% homogeneity. This size can be considered satisfactory, since calibrations and tests may be carried out easily under this condition.

The inherent filtration was also evaluated from the measurement of the first HVL. From the HVL value at 60 kVp and without additional filters, the inherent filtration can be determined according to reference 7. Thus, the HVL calculated was 1.32 mmAl, which corresponds to 1.21 mmAl of inherent filtration.

The X-ray spectra measurements performed with the CdTe detector were obtained at 50, 60 and 70 kVp tube voltages, with 1.53 mmAl additional filtration. These spectra, without correction, were compared with the ones from the commercial dental units at the same tube potentials (Fig. 5 to 7).

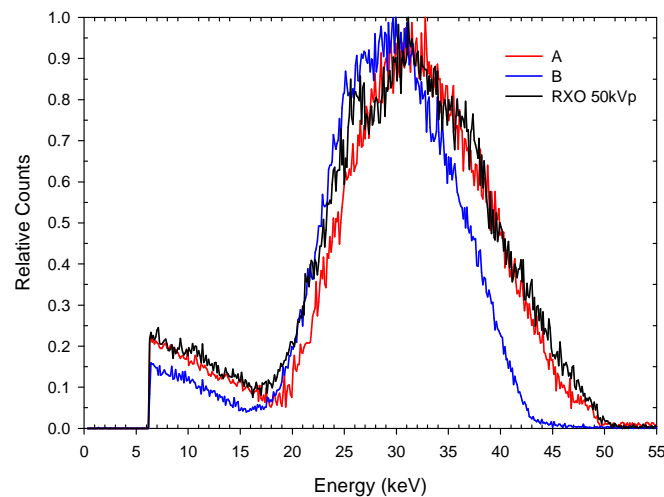


Figure 5. X-ray spectra from 50 kVp X-ray units.

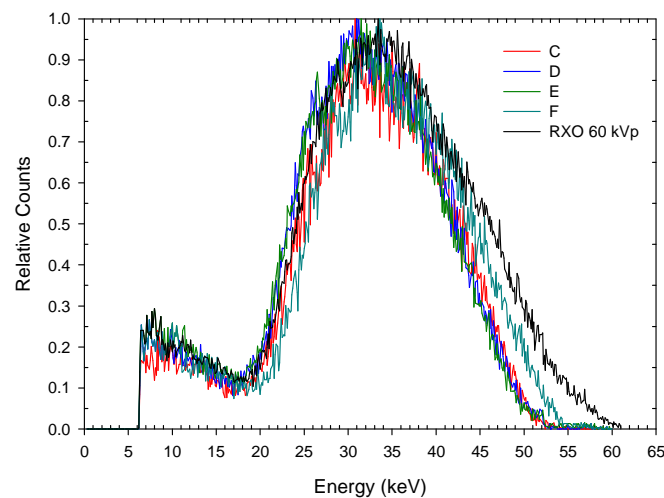


Figure 6. X-ray spectra from 60 kVp X-ray units.

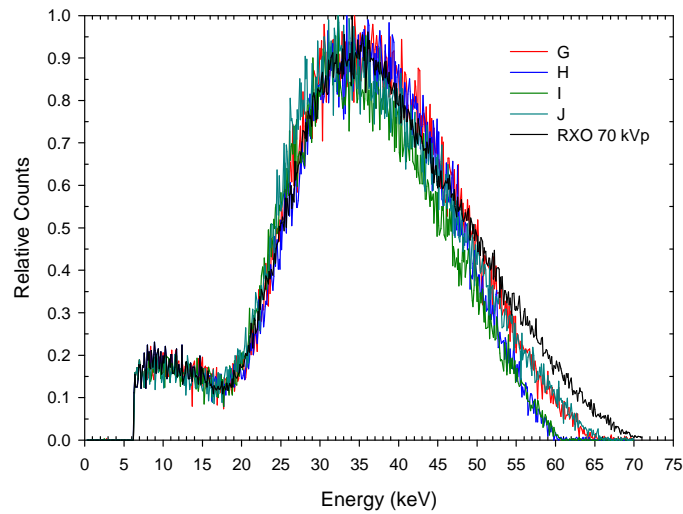


Figure 7. X-ray spectra from 70 kVp X-ray units.

In relation to the maximum photon energy, the group of 50 keV (Fig. 5) showed the best correlation between the spectra from the commercial and the variable potential X-ray units. The maximum deviations of the spectra from commercial X-ray units in relation to the reference X-ray unit were 9.0%, 12.6% and 12.9% for 50, 60 and 70 keV groups, respectively. These results show that commercial X-ray units have a significant variation in relation to the nominal kVp. On the other hand, the variable potential X-ray unit system allows the adjustment of kVp and mA and the applied voltage is controlled by means of a special stabilizer.

The spectra, without correction, from the variable potential X-ray unit were called “standard spectra” for dental X-ray beams generated at 50, 60 and 70 kVp. In order to define dental X-ray qualities for use for medical and radiation physics purposes, these spectra were corrected by the stripping method described by Morales et. al. [8]. The corrected spectra are shown in Fig. 8 and the dental X-ray qualities parameters evaluated are listed in Table 2.

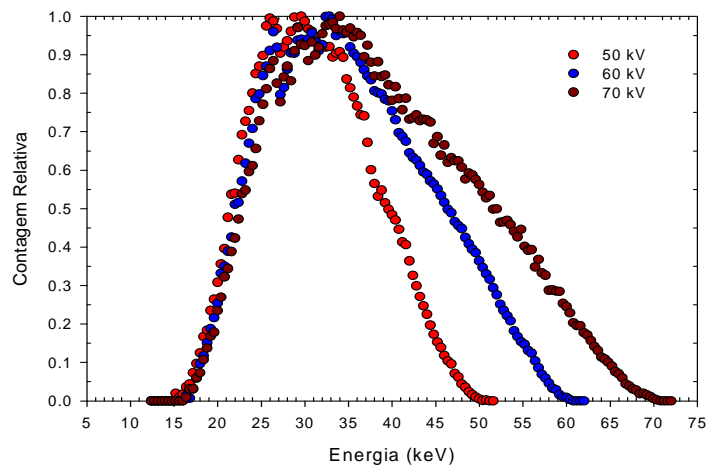


Figure 8. Corrected X-ray spectra from the reference dental X-ray unit.

Table 2. Dental X-ray qualities for test and calibration purposes for the variable potential X-ray unit.

Radiation Quality	Tube Potential (kV)	Total Filtration (mmAl)	1 st HVL (mmAl)	2 nd HVL (mmAl)	Mean photon Energy (keV)	Air-Kerma rate at 1 m (mGy/h)
DRQ 1	50	2.74	1.37	1.72	31.07	68.79±0.66
DRQ 2	60	2.74	1.63	2.08	35.29	105.43±1.0
DRQ 3	70	2.74	1.92	2.63	38.90	148.88±1.4

The total filtration of the reference X-ray unit was 2.74 mmAl (1.21 mmAl inherent filtration plus 1.53 mmAl additional filtration). The corresponding values for the commercial X-ray units ranged from 2.50 to 3.81 mmAl. According to the ANVISA criteria, the minimum total filtration for dental X-ray units up to 70 kVp tube potential is 1.5 mmAl.

The 1st HVL ranged from 1.37 to 1.92 mmAl for the variable potential X-ray unit, and from 1.16 to 1.95 mmAl for the commercial X-ray units. According to the Brazilian legislation [3], the minimum accepted 1st HVL values are 1.2 mmAl (at 51 kVp), 1.3 mmAl (at 60 kVp) and 1.5 mmAl (at 70 kVp). The 2nd HVL ranged from 1.72 to 2.63 mmAl for the variable potential X-ray unit and from 1.44 to 2.45 mmAl for the commercial X-ray units.

These results show a good agreement between the dental X-ray qualities from the variable X-ray unit and the commercial dental X-ray quality parameters.

3.3 Constant Potential X-ray Unit

The reference spectra from the variable potential dental X-ray unit were utilized for determining a new set of X-ray qualities for the constant potential X-ray equipment. The spectra for the same tube potential and total filtration in both constant and variable X-ray equipments do not match, because their rectification systems are different (one is half-wave rectification and the other is constant potential).

In order to define similar spectra for both units (in term of their X-ray mean energies), changes in total filtration and potentials applied to the X-ray tube from the constant potential X-ray equipment were evaluated by means of the Report 78 Spectrum Processor program developed by Institute of Physics and Engineering in Medicine – IPEM [9]. The X-ray spectra simulated by this software, from the tube potential and total filtration inputs, were implemented in the constant potential X-ray unit aiming to obtain the experimental spectra.

The comparisons for both spectra obtained at 50, 60 and 70 kVp from the variable and constant potentials X-ray units are shown in Fig. 9a to 11a. In order to establish the similar mean photon energy, the tube potential was decreased and the total filtration was increased for the constant potential X-ray unit. The differences in the spectra areas at 50, 60 and 70 kVp for both units were 0.9%, 3.1% and 7.2%, respectively.

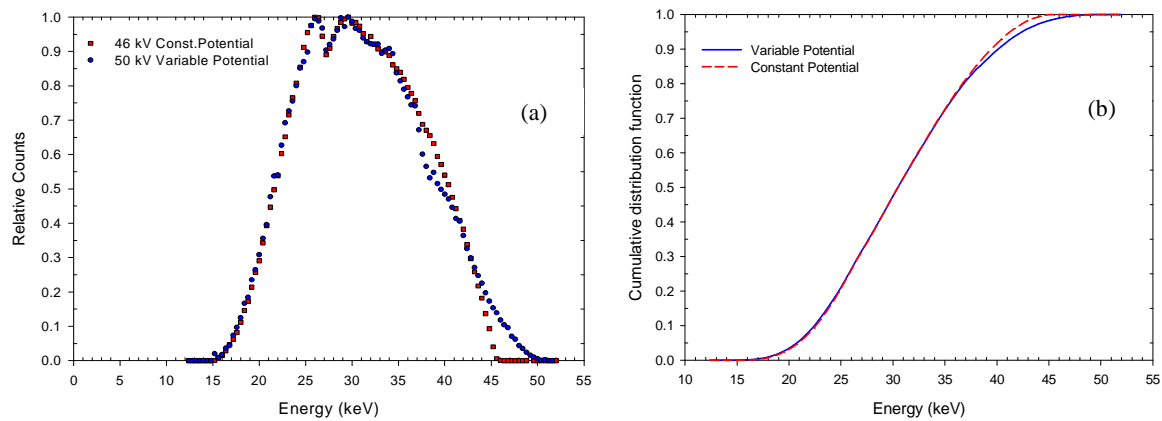


Figure 9. (a) X-ray spectra from 46 and 50 kVp X-ray units; (b) Cumulative distribution functions from 46 and 50 keV spectra.

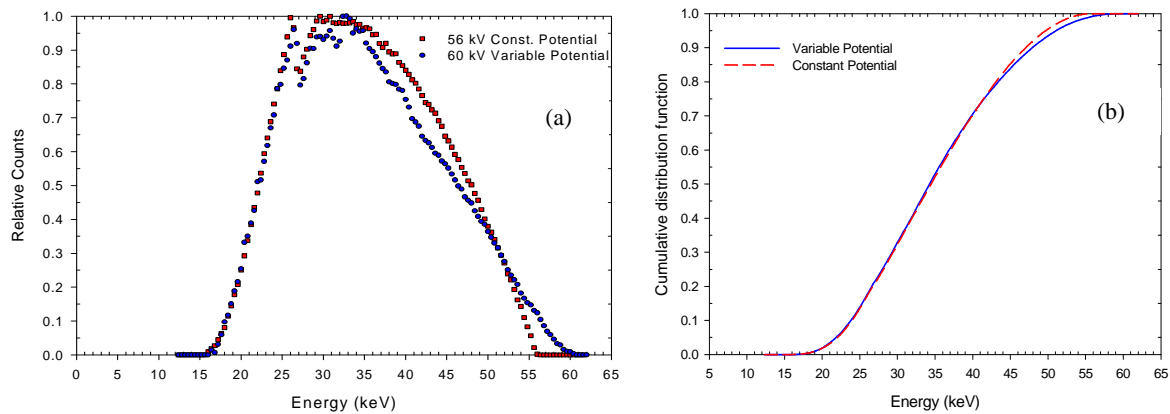


Figure 10. (a) X-ray spectra from 56 and 60 kVp X-ray units; (b) Cumulative distribution functions from 56 and 60 keV spectra.

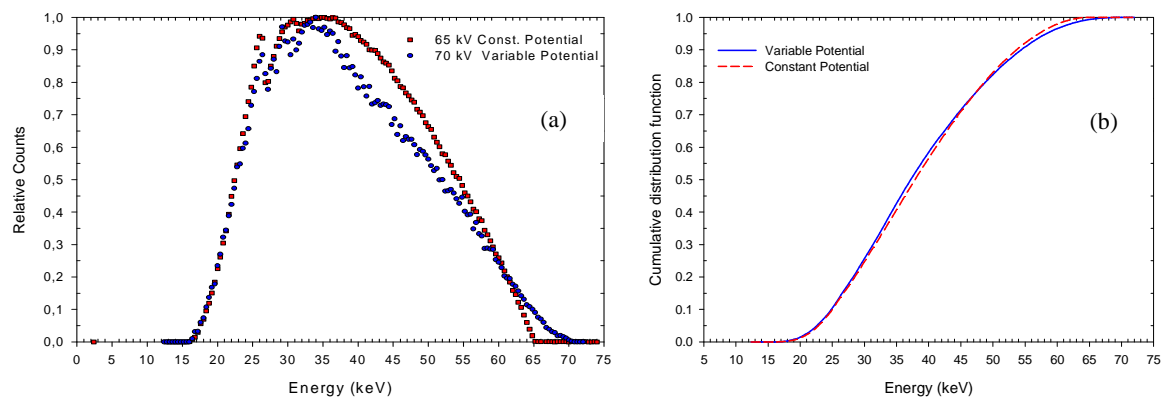


Figure 11. (a) X-ray spectra from 65 and 70 kVp X-ray units; (b) Cumulative distribution functions from 65 and 70 keV spectra.

The Kolmogorov–Smirnov (K–S) statistical test was performed to determine if the two spectra data sets (Fig. 9a to 11a) differ significantly. Thus, each spectrum data in these figures was transformed into a cumulative distribution function (Fig. 9b to 11b).

The null distribution of the K–S statistic is calculated under the null hypothesis (that the samples are drawn from the same distribution). In this way, the K–S statistic quantifies the maximum distance (Dcalc) between the empirical distribution functions of two samples, F(x) and S(x), according to the equation:

$$D_{\text{calc}} = \text{Max} |F(x) - S(x)| \quad (1)$$

The hypothesis regarding the distributional form is rejected if the test statistic (Dcalc) is greater than the critical value (Dtab) obtained from tables for the K–S test. One of them is the reference 10. The K–S test results showed that all spectra are similar at the 0.01 significance level (Table 3).

Table 3. Kolmogorov–Smirnov test results.

Spectra	Sample size (N)	Significance level (α)	Dcalc (equation 1)	Dtab $1.63/(N)^{1/2}$	Hypothesis result
Figure 9b	99	0.01	0.023	0.164	Accept
Figure 10b	124	0.01	0.020	0.146	Accept
Figure 11b	149	0.01	0.022	0.134	Accept

Finally, the dental X-ray quality parameters evaluated for the constant potential are listed in Table 4. The mean photon energies presented in this Table are close to the values shown in Table 2. This fact, together with the statistical results, show that these X-ray qualities can be used for test and calibration purposes.

Table 4. Dental X-ray qualities for test and calibration purposes for the constant potential X-ray unit.

Radiation Quality	Tube Potential (kV)	Total Filtration (mmAl)	1 st HVL (mmAl)	2 nd HVL (mmAl)	Mean photon Energy (keV)	Air Kerma rate at 1 m (mGy/h)
DRQ 1	46.0	2.96	1.68	2.24	30.96	78.41±0.75
DRQ 2	56.0	2.96	2.08	2.72	35.23	131.73±1.3
DRQ 3	65.0	2.96	2.41	3.28	38.92	184.03±1.7

4. CONCLUSIONS

Dental X-ray qualities for test and calibration purposes were investigated. The commercial dental X-ray spectra, without corrections, were compared with the ones from the variable potential dental X-ray unit at the same tube potentials. The results show a good agreement among them. Thus, the corrected spectra were utilized to define the X-ray qualities in this X-ray unit.

The X-ray qualities spectra were utilized for determining a new set of X-ray qualities for a constant potential X-ray equipment. The spectra obtained for both variable potential and constant potential X-ray units were compared. The mean photon energies and the statistical test indicated that the spectra present a good agreement.

These X-ray beam qualities, implemented in two X-ray laboratories (one with the variable potential X-ray equipment and other with potential constant X-ray equipment), should be used for test and calibration purposes involving scientific studies and services. They represent the first approach in order to establish Reference X-ray Qualities for the dental area in Brazil.

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