Quality control measurements for mobile X-ray unit through a solid state detector

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Abstract. The tests of quality control for equipments used in radiology departments are essential both functionality of the equipment and for accuracy dose in the patient. The mobile digital x-ray equipment has as one of its main benefits its mobility, which allows the carrying out of examinations in the patient’s bed that has certain physical limitations. It should be taken into account, however, that hospital beds were not normally designed with the necessary details to protect the radiological environment from where radiography procedures are performed. Therefore, the need for an efficient quality control of the equipment is justified, the preliminary measurements of the present work were based on ANVISA’s guide 453 from Brazil, regarding conventional radiography equipment. Thus, some quality control tests were determined using the solid state dosimeter. For the accomplishment of this study, the tests of tube voltage accuracy and reproducibility, half value layer (HVL) and effective energy, air kerma and air kerma rate were performed, with their associated errors calculated. The tests were performed with the aid of the black piranha apparatus to obtain the values of tension, dose and HVL. The obtained results from the performance of each test showed that all are in agreement with the ANVISA’s guide 453 recommendation, and could be applied in a possible development of a quality control guide specific to the characteristics of a mobile radiograph.

Keywords: Quality assurance; Dosimetry; radiological protection; mobile X-ray; solid state dosimeter

1. Introduction

The functional integrity of an X-ray unit is assurance through the performing of quality control tests, periodically. In Brazil, the Ministry of Health established the ordinance No. 453/98 MS/SVS on June 1st in 1998, in which regulates the operation of diagnostic services medical and dental [1]. The ordinance 453 includes difference tests for conventional X-ray mammography, X-ray equipment with fluoroscopy and Computed Tomography (CT) units. Currently, the X-ray technology has developed several variations of imaging technologies that allow instant high-quality X-ray image processing and greater mobility [2]; these technologies are not contemplated in ordinance 453. Mobile units for radiography emerged from the need to overcome limitations
from patients with physical restrictions, especially those who are in the intensive care unit. In this perspective, the operating environment of the mobile X-ray is carried to the patient’s bed [3]. Hence, it is essential that there be a rigor and competence in the quality control tests for this kind of equipment, since hospital rooms were not designed with the same purpose of radiological protection as the radiography rooms [4]. During the examination with the X-ray unit, there is a relevant concern regarding the dose limits of the occupationally exposed individual. In contrast, from a radiological protection point of view, there is not yet a specific national or international protocol for mobile X-ray equipment. Due to the lack of a specific quality control protocol for mobile X-ray equipment, the tests are performed based on ordinance 453, which recommended tests for conventional x-ray units. The organizations like International Electrotechnical Commission, IEC-61674 [5], International Commission On Radiation Units And Measurements, ICRU Report 74 [6], International Atomic Energy Agency, TRS 457 [7], American Association of Physicists in Medicine, Report 74 [8] recommend the ionization chamber as standard dosimeter, and also solid state and semiconductor dosimeters must be in compliance with these documents to perform the quality control tests.

The overall goal of the present work was used a Black Piranha detector (BP), a solid state dosimeter, due is detector provides easy and fast X-ray quality control [9, 10, 11, 12]. To determine tests as part of quality assurance: tube voltage accuracy and reproducibility, half-value layer, effective energy analysis and testing of the air kerma rate as a function of the mAs were shown in the present work.

2. Materials and Methods

The experimental measurements were carried out with mobile X-ray unit (Shimadzu) with digital radiology system, model MobileArt Eco, with characteristic: maximum tube voltage of 125 kV and maximum current of 160 mA, focal point of 0.7 mm, Rhenium Tungsten-faced on Molybdenum as target material and an angle of 16°. A black piranha detector (RTI Electronics), calibrated for energies form 35–160 kVp with 1.5% of uncertainty, was used to measure some parameters for beam quality assurance for tube voltages ranging from 40 to 120 kVp and alternating the mAs(product of the tube current by the time of acquisition of the image) for three values of: 1.1; 3.2 and 16. The choice of these values are associated with the pre-configured kV and mAs settings for medical examinations like extremity (hand, foot, etc.), chest and abdomen, respectively. The BP detector was positioned perpendicularly of the beam in source-detector distance of 60 cm and the field size was delimited according to the orientation on dosimeter, ensuring the sensitive area.

2.1. Tube voltage accuracy and reproducibility

For quality control of clinical X-ray units the measurement of tube peak kilovoltage is the most important due to small variations in kVp values can increase the absorbed doses in patient and at the same time can compromise the image quality; it is known that there is squared dependence between air kerma and kVp, approximately [13, 14, 15].

The kVp accuracy was determined through the equation 1, where D (%) is the uncertainty relative to the nominal values, nominal kVp (kVpn) and average kVp (kVpav). The mean values of kV were obtained through arithmetic mean of 4 measurements for each mAs and the selected kVpn. The ordinance 453 recommended that the value obtained from equation 1 must be in an interval of ±10%, which is adopted in the standard for conventional x-ray modality.

\[
D(\%) = 100 \frac{kV_{p_n} - kV_{p_{av}}}{kV_{p_n}}
\]  

(1)

The reproducibility of the kVp values were obtained using the equation 2, which is also available in the ordinance 453, which kVpmax and kVpmin are the maximum and minimum
value of voltage readings. The standard requires, from the ordinance recommends values of reproducibility, R(%) 10%. The results obtained of reproducibility related to selected kVp values (40, 50, 60, 70, 88, 95, 104, and 120) and the values of mAs at each kVp (1.1, 3.2 and 16) are shown in Table 1 and Table 2.

\[ R(\%) = 100 \frac{kVp_{\text{max}} - kVp_{\text{min}}}{kVp_{\text{max}} + kVp_{\text{min}}} \]  

2.2. Half Value Layer (HVL)

This test was performed in two ways: First, the detector was positioned at source-detector distance of 60 cm. The exposures were performed for the highest mAs used in this work, 16 mAs, varying the values of kVp: 40, 88 and 120. A similar method was published by Reena Sharma et al [16]. A second modality was applied for the HVL measurement, under the same conditions of irradiation of the first modality adding aluminum plates (with a purity of 99% with thicknesses of 0.1 mm to 2 mm) on the piranha detector. The plates were added between the detector and the tube window until the dose value marked by the detector was reduced by half of the dose value. The obtained value related to HVL (mmAl) was given by the sum of the thicknesses of the plates used.

2.3. Effective energy, air kerma and air kerma rate

For determination the effective energies was followed by the methodology shown by Dennise Magill [11]. The HVL obtained values were related to the linear attenuation coefficient of a given attenuator material, as shown in the next formulation:

\[ HVL = \frac{\ln2}{\mu} \]  

From the calculated values of the linear attenuation coefficient was determined the effective energy through the figures of the photon energy vs linear attenuation coefficient for each attenuator material. The data figures are available in the NIST – Physical Measurement Laboratory [17]. Thus, through the implementation of a code in PythonTM language, the effective energies associated to HVL values CSR of each of the three mAs for the associated kVs were calculated. Values of air kerma rate and air kerma rate were obtained in real time with the BP, choosing three different values mAs: 1.1, 3.2 and 16, and for 40, 60, 70, 88, 104 and 120 kV values.

3. Results and Discussion

3.1. Tube voltage accuracy and reproducibility

According to the ordinance 453, the test for accuracy and reproducibility of the tube voltage is recommended for X-rays units. The minimum frequency associated with this test is annual, except in cases where the device goes through repairs, where the test must be repeated. The table 1 shows the values of D% and R% for each Nominal kVp and mAs evaluated.
Table 1. D% and R% with Nominal kVp and mAs

| Nominal kVp | mAs | D(%) | R(%) | Nominal kVp | mAs | D(%) | R(%) |
|-------------|-----|------|------|-------------|-----|------|------|
| 40          | 1,1 | 4,02 | 1,12 | 88          | 1,1 | 3,02 | 0,28 |
|             | 3,2 | 3,80 | 1,56 |             | 3,2 | 2,12 | 0,33 |
|             | 16  | 3,41 | 1,30 |             | 16  | 1,77 | 0,09 |
| 50          | 1,1 | 3,24 | 2,32 | 95          | 1,1 | 3,79 | 0,34 |
|             | 3,2 | 3,09 | 0,81 |             | 3,2 | 3,15 | 0,12 |
|             | 16  | 2,55 | 0,60 |             | 16  | 3,10 | 0,09 |
| 60          | 1,1 | 4,87 | 0,60 | 104         | 1,1 | 1,50 | 0,11 |
|             | 3,2 | 2,99 | 0,14 |             | 3,2 | 0,89 | 0,20 |
|             | 16  | 2,11 | 0,19 |             | 16  | 0,79 | 0,12 |
| 70          | 1,1 | 4,58 | 0,37 | 120         | 1,1 | 2,58 | 0,33 |
|             | 3,2 | 3,34 | 0,22 |             | 3,2 | 2,26 | 0,18 |
|             | 16  | 2,96 | 0,31 |             | 16  | 2,24 | 0,22 |

From the values shown in table 1 can observe that the highest values both voltage accuracy and reproducibility are given to lower values mAs for all kV selected. The authors assumed that this phenomena can be caused by low production of photons and the probability of interacting with the detector decreases for low kV selected.

The accuracy and reproducibility values shown in table 1 for each mAs associated with a specific kVp are in the interval proposed by the ordinance 453 [1], with maximum value of approximately 5% and 2.35% for accuracy and reproducibility, respectively. Even though these limits were originally proposed to conventional X-ray units for the equipment used in this work the results are in accordance with the ordinance. The international organizations IEC-61674 [5] recommended variation of $\pm 5\%$ accuracy and $\pm 0.5\%$ reproducibility. The established performance for accuracy test from the AAPM [8] also was of $\pm 5\%$.

An analysis of the values from the difference values of mAs and kVp were realized when the value of mAs increased the value of tend to the nominal kVp. This behavior was verified for all values of mAs and kVps. The figure 1 shows the quadratic behavior for 40 kV.
There are no similar behavior effects for there are no publications in the literature that co-exist with this effect. In the same way, the same behavior was observed for the other nominal kVps (50, 60, 70, 88, 95, 104, 120).

3.2. Half value layer (HVL)
According to the ordinance 453 the minimum frequency to perform this test must be annually, with the exception of maintenance and repairs the equipment. The HVL test, whose objective is to verify the quality of the X-ray beam, was performed with two forms: one method using values of kVp chosen from the X-ray unit, another one it inferred values of HVL through adding aluminum plates on the detector.

The analysis for the two methods are shown in Tables 2 and 3, with uncertainties lower than 4% for the values of HVL of table 2 and 0.5mm for table 3. Compared both values (from table 2 and 3) through a relative percentage error was found 3.44%, 2.77% and 0.4%, relative to the kVp: 40, 88 and 120, respectively.

Table 2. HVL measurement for each kVp

| kVp | kV Average | HVL(mmAl) |
|-----|------------|-----------|
| 40  | 38.82      | 1.46      |
|     | 38.84      | 1.47      |
|     | 38.73      | 1.41      |
| 88  | 86.28      | 3.67      |
|     | 86.21      | 3.63      |
|     | 85.43      | 3.52      |
| 120 | 117.28     | 5.05      |
|     | 117.32     | 5.01      |
|     | 116.90     | 4.88      |

Figure 1. Quadratic effect between 40 kV and 1.1, 3.2 and 16 mAs
### Table 3. HVL measurement for each kVp

| kVp | HVL(mmAl) |
|-----|-----------|
| 40  | 1,5       |
| 88  | 3,5       |
| 120 | 5,0       |

#### 3.3. Effective energy and air kerma

Values of the effective energy obtained through linear attenuation coefficient and the HVL values, for different kVp and mAs, are shown in Figure 2.

![Figure 2](image)

**Figure 2.** Effective energy values vs different kV values, and three mAs

From the determined values for the effective energy showed similar behavior from the literature [18], though there are no comparative results in others papers for this type of equipment and nor of energy used. As an aspect, for more increase effectiveness is proportional to increase of the kV values. Figure 2 shows the effective energy values greater relative for 16 mAs, compared with the other two values of mAs, the major difference was of 1,60 % for 70 kVp.

Values of air kerma are shown in figure 3 and figure 4 showed the air kerma rate values with different behavior related to the kV values selected in these tests.
Values of air kerma and air kerma rate are more prevalent for high kV and mAs values, as shown in the figures above. For different mAs, the air kerma values increase proportionally to the mAs, although this behavior is not the same for the air kerma values, when the lower
values of mAs have a linear relationship with air kerma and for high value shown a tendency of quadratic dependence.

4. Conclusion
In general, it can be concluded that for the quantities dose, X ray tube voltage, HVL the values indicated by the measuring devices go beyond the limits of accuracy stated in the corresponding manuals. HVLs should preferentially be measured by using well established conventional methods based on the use of calibrated ionization chambers and sets of appropriate aluminium absorbers [7]. The results of this work demonstrate the need for international standards that define further requirements on the performance of semiconductor based, multi-parameter measuring devices, especially for those quantities that are essential for quality assurance in diagnostic radiology for the mobile X-ray unit.

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