Quality Control Implementation on Digital Radiography Equipment at Fundación Valle Del Lili

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Abstract
Either national regulatory process or international accreditation process obligates the healthcare institutions to implement a quality control program to the digital radiography equipment. These are made in order to assurance the high quality image and to reduce the unnecessary exposure doses on people. In radiology, a good diagnostic is related with the high quality of the image. In this research it is showed the results of 90 quality control tests performed on three different equipment located at Fundación Valle del Lili (FVL). These tests were particularly: physical location inspection, geometrical features, quality of the beam, automatic exposure control (AEC), quality image in digital systems, dose measurement systems, etc. Outcomes were compared with manufacturer’s reference values. A percentage of 92.23 % were found out in optimal conditions, this means 83 checks. The Dose Area Product (DAP) tests’ results are in a range between 5.57 to 2574.70 μGy*m², which are reported in the literature. Those tests that not belong in the reference values, were subject to corrective actions and it is generated a feedback about the possible failures.

Keywords: Quality Control; Digital Radiography; Dose Area Product; RaySafe X2.

1. Introduction
Nowadays there are a lot of medical exposures in radiographic imaging in Colombia and worldwide. We performed about 30 quality control tests in three radiographic digital equipment in a diagnostic images center at Fundación Valle del Lili headquarters. The principal goal was to verify the appropriate performance of the digital radiographic equipments, assurance of the radiological protection rules and Quality assurance of the image quality. The equipment was Siemens models: Aristos, Ysio and Multix Fusion. Resolution 0482 of 2018 by Health ministry in Colombia regulates quality controls of ionizing radiation equipment and radiological protection on the staff. It is indispensable that health institutions staff make continuously quality control tests to these equipments in order to confirm optimal conditions. Quality administration in the x-ray machine is the management of the quality control procedures, this includes making sure that the equipment monitoring and performance evaluation is properly done, assessed and recorded. It also involves following up with necessary corrective measures [1], [2]. Some of those studies revealed that QC can reduce patient dose by at least 30 % [3]. Quality control tests related in this work, were based on “Protocolo de control de calidad en radiodiagnóstico del acuerdo regional de cooperación para la promoción de la ciencia y la tecnología nuclear en América latina y el caribe (ARCAL)” which is supported by International Atomic Energy Agency (IAEA) and the “Protocolo español para el control de calidad en radiodiagnóstico (SEFM)”. However, some tests were adjusted to our needed. In a nutshell, it was made 30 tests for every equipment; general parameters, geometrical parameters and quality of the beam were performed using ARCAL guidelines. Such as: radiometric measurements, leakage radiation, accuracy and repitibility of the nominal kV, etc. On the other hand, Automatic Exposition Control (AEC) Tests and imaging quality were made taken the guidelines given by SEFM. Such as: AEC repetibility, uniformity of the image, distortion of the geometry and size of the field, response of
the detector, special resolution, sensibility of the contrast, noise, things in the image, etc. All these previous tests were made by the medical physics and radiological protection office. It is important to point out that around 95% of the tests were successful.

2. Materials and Methods

A total of 90 tests were carried out in the 3 digital radiography equipment (30 for each equipment). Figure 1 represents the different parameters and its percentage in the tests. Exposition dose measurement, dose rate, kVp, Half Value Lawyer (HVL), total filtration and exposition time were made with the RaySafe X2 equipment. Pro-Digi Phantom by RaySafe was used in tests such as: homogeneity, contrast resolution, special resolution, dynamic range, position and effective size of the field of radiation, alienation of the beam and collimation. Another relevant thing is the Alderson Radiation Therapy Phantom (ART) which was used to measure dispersion. Besides, aluminum filters and PMMA slices also were used.

![Test parameters](image)

*Figure 1. Number of the overall tests for each parameter.*

**General parameters.** 1. Physical inspection of the equipment and in its facilities: mainly it is checked all the acquisition room, verify the overall conditions of the equipment mechanical and electrical. 2. Radiometric measurements: whit a Geiger instrument (Fluke Biomedical ASM-990) is measured the dose rate close to the equipment facilities in order to verify exposure levels of the staff and public.

3. Leakage radiation: the goal is to verify the good conditions of the housing of the tube; the ART was indispensable in this case.

\[ L_R = \frac{l_f}{l_e} L_0 \]  

Where: \( L_R \): leakage dose rate, \( l_f \): maximum current, \( l_e \): Used current, \( L_0 \): conversion factor to mGy/h.

**Geometric parameters.** 4. Perpendicularity of the radiation beam: center of the beam must fit in the reticulum center. 5. Alienation of the luminous field with the radiation field: luminous field must be the same with the radiation field.

**Quality of the beam.** 6. Accuracy of the nominal value of the tube tension: in order to evaluate the accuracy for each value of the tension

\[ d(\%) = 100 \frac{kV_{ind} - kV_{med}}{kV_{ind}} \]
7. Repeatability of the nominal value of the tube tension”: in order to evaluate the repeatability of different values of the X-Ray tube.

\[ d(\%) = 100 \frac{kV_1 - kV_2}{(kV_1 + kV_2)/2} \]  

(3)

8. Half Value Lawyer: verify if the filtration of the beam is adequate.

\[ HVL = \frac{-F \ln 2}{\ln(L/L_0)} \]  

(4)

Where: \( F \): Thickness Al filter, \( L \): exposure dose without filter, \( L_0 \): exposure dose with filter.

9. Repeatability of the exposure: evaluate the constancy of the exposition in different shots (KERMA constancy)

\[ R(\%) = 100 \frac{L_{\text{Higher}} - kV_{\text{less}}}{(L_{\text{Higher}} + kV_{\text{less}})/2} \]  

(5)

10. Linearity of the exposition: evaluate the change of the exposition in comparison to the current.

\[ L(\%) = 100 \frac{R_1 - R_2}{R_1 + R_2} \]  

(6)

11. Performance of the exposition”: evaluate the constancy of the KERMA in air for a mAs given, linearity and intensity of the performance.

12. Accuracy of the exposure time: corroborate the accuracy of the indicator of the exposure time

\[ d(\%) = 100 \frac{kV_{\text{ind}} - kV_{\text{med}}}{kV_{\text{ind}}} \]  

(7)

13. Repeatability of the exposure time”: verify the repeatability of the indicator of the exposure time.

\[ R(\%) = 100 \frac{L_{\text{Higher}} - kV_{\text{less}}}{(L_{\text{Higher}} + kV_{\text{less}})/2} \]  

(8)

**AEC for digital systems:** 14.AEC repeatability: determine the constancy in the system of AEC, use equation number (8).

Figure 2. AEC test using the ART phantom.
15. Compensation of the AEC to different thickness*: evaluate the compensation if the AEC system with the changes in the thickness of the receptor, 16. Compensation of the AEC for different voltages and currents.

*Grid, 17. Exposition factor of the grille**: evaluate the exposition factor of the grilles having measured doses values in the beam and at the same point in the plane of the image.

\[ f = \frac{D_1 f_1}{D_2 f_2} \] 

Where: \( D_1 \) y \( D_2 \) Dosis at the same axis, \( f_1 \) y \( f_2 \) distance to the focus.

18. State and movement of the grille: identify the variances of the grille for different positions and uses.

Image quality in digital systems: 19. Uniformity of the image: A uniform image and without artifacts.

\[ d(SNR) = \frac{MVP}{SDP} \] 

Where: \( MVP \): Medium value pixel, \( SDP \): standard deviation pixel

20. Distortion of the geometry and size of field: verify that the nominal size of the detector is equal with the showed in the monitor; also to corroborate the precision of the measuring tools, 21. Dynamic range or function of the detector response: determine the relation between the exposition and the value of the pixels, 22. Special resolution: evaluate the limit of the resolution, 23. Sensibility of the contrast: verify the least possible contrast and its uniformity over the time, 24. Background noise in the detectors: verify that the image system in not exposed, 25. Noise: evaluate the spectrum power noise (SPN) and to characterize the noise spectrum of the detector

\[ NNPS = \frac{NPS}{(kerm)^2} \] 

Where: \( NNPS \): Normalized NPS.

26. Elements in the image: watch the image to do not have strange things, 27. Evaluation of the uniformity in the illumination of the visualization systems: here it’s verified the luminance and illuminance of the screen where the images are shown.

Doses measurement system: 28. Dose calibration in the detector: determine the accuracy of the provided dose indicator in comparison with the given exposition, 29. Verification of the performance of the measurement system: evaluate the difference between the dose area and the equipment, 30. Patient surface dose: estimate the skin entrance dose in the more frequently exams. To finish it has an assessment of the quality control program.

3. Results
In the first test it showed that all the equipments are in successful conditions both mechanical and electrical.

Table 1. (Test 2)
Radiometric measurements

| Parameters       | Aristos | Multix | Ysio  |
|------------------|---------|--------|-------|
| kV               | 125     | 125    | 125   |
| mAs              | 50      | 50     | 50    |
| controlled area  | 0,084   | 0,075  | 0,061 |
| public area      | 0,0022  | 0,0014 | 0,0025 |
Figure 3. Aristos, Multix e Ysio’s leakage radiation.

Taking the results of the test 4, the variable that is evaluated is the peak of the cone from the Pro-Digi Phantom. This value must be within 1.5° that is the tolerance range, the three equipment succeeded with this test.

Table 2. (Test 5)
Region of interest (ROI)
Line up of the light field with the radiation field

|        | Aristos (mm) | Multix (mm) | Ysio (mm) |
|--------|--------------|-------------|-----------|
| ROI    | 260 x 260    | 240 x 180   | 240 x 240 |
| UP     | 1.0          | 1.4         | 2.1       |
| Down   | 1.3          | 1.1         | 0.9       |
| Left   | 3.2          | 2.4         | 0.7       |
| Right  | 2.1          | 3.0         | 1.2       |

Table 3. (Test 7) Repeatability of the voltage

| kV Test | Aristos | Multix | Ysio |
|---------|---------|--------|------|
| 80      | 79.4    | 80.7   | 79.1 |
| 80      | 80.6    | 80.8   | 79.6 |
| 80      | 80.1    | 80.7   | 79.4 |
| 80      | 80.4    | 80.6   | 79.7 |
| R(%)    | 1.5     | 1.24   | 1.01 |

Table 4. (Test 8) Half Value Layer

| kV   | Thickness (mm) | Aristos(mmAl) | Multix(mmAl) | Ysio(mmAl) |
|------|----------------|---------------|---------------|-------------|
| 80   | 1.5            | 8.02          | 8.01          | 8.06        |
| 80   | 1.5            | 8.15          | 8.07          | 8.09        |
| 90   | 1.5            | 8.83          | 8.84          | 8.94        |
| 100  | 1.5            | 9.39          | 9.32          | 9.54        |
| 125  | 1.5            | 10.2          | 10.1          | 10.9        |
Table 5. (Test 9) Repeatability of the exposition

| kV   | mAs | Aristos | Multix | Ysio |
|------|-----|---------|--------|------|
| 123.2| 1.8 | 3.776   | 3.612  | 3.587|
| 122.7| 1.8 | 3.781   | 3.597  | 3.589|
| 124.0| 1.8 | 3.821   | 3.606  | 3.584|
| 123.9| 1.8 | 3.821   | 3.609  | 3.589|
| 124.7| 1.8 | 3.823   | 3.602  | 3.579|
| R (%)|     | 1.23    | 2.02   | 1.64 |

It is found a mean performance function (test 11), beginning at 10 mAs and changing kV from 50.5 to 124 and applying a polynomial of second order in order to find a mathematical description between E (V) (efficiency) and kV, then we have:

$$E(kV) = 0.00243kV^2 + 0.1508kV - 8.18$$

![Efficiency curve](image)

Figure 4. Mean performance function based in kV values (Aristos).

Table 6. (Test 13) Repeatability of the exposition Time

| mAs | Aristos | Multix | Ysio |
|-----|---------|--------|------|
| 250 | 254.4   | 247.9  | 246.5|
| 250 | 254.6   | 247.8  | 247.3|
| 250 | 254.1   | 246.3  | 247.6|
| 250 | 254.2   | 248.5  | 247.3|
| 250 | 275.1   | 247.8  | 247.5|
| R (%)| 3.96    | 3.10   | 2.87 |

Test (14) Repeatability of the ACE

![Image](image)

Figure 5. Standard acquisition for skull with ACE and kV of 80.
Figure 6. kV vs Time (Blue) y Dose rate vs Time (Red) Aristos. (Test 6 y 12)

Figure 7. Quality image control tests kV=90, mAs =1.8 DFD=180 cm (taken from Aristos equipment).

Table 7. Uniformity of the image

| Zone ROI   | MVP    | SDP   | SNR  | MVP    | SDP   | SNR  | MVP    | SDP   | SNR  |
|------------|--------|-------|------|--------|-------|------|--------|-------|------|
|            | Aristos|       |      |Multix |       |      | Ysio   |       |      |
| Center     | 2589.833 | 198.16 | 3.98 | 2789.12 | 274.62 | 2.45 | 2832.98 | 267.54 | 2.76 |
| Up right   | 2590.667 | 338.52 | 3.34 | 2756.62 | 285.36 | 2.36 | 2852.23 | 298.42 | 2.53 |
| Up left    | 2597.833 | 218.97 | 3.64 | 2776.67 | 268.12 | 2.47 | 2781.63 | 275.58 | 2.59 |
| Down right | 2501.667 | 395.18 | 3.77 | 2853.12 | 273.94 | 2.98 | 2963.53 | 269.39 | 2.92 |
| Down left  | 2511.000 | 346.85 | 3.18 | 2654.23 | 278.28 | 2.73 | 2773.48 | 294.61 | 2.43 |

Figure 7 represents a typical quality control image. There are three sections well separated. Region (2) is the special resolution; it got a value of 3.7 LP/mm, with a mean of 3.65 LP/mm, the result is consistent with the size of the pixel. Region (3) represents contrast resolution, it was found images
between 1.2 % y 2% for low contrast. Region (1) shows the variation of the number of pixels in comparison with the gray level.

Table 8. Background noise

| Parameters | Aristos | Multix | Ysio |
|------------|---------|--------|------|
| kV         | 50      | 50     | 50   |
| mAs        | 0.5     | 0.5    | 0.5  |
| (μGy * m²) | 0.25    | 0.17   | 0.04 |
| VMP        | 3568.93 | 3254.32| 3493.78|

Table 9. Surface Dose

| Parameters | Aristos | Multix | Ysio |
|------------|---------|--------|------|
| kV         | 80      | 80     | 80   |
| mAs        | 1.8     | 2.0    | 2.0  |
| K(μGy)     | 22.17   | 24.83  | 23.34|
| IE         | 2115    | 2254   | 2275 |

4. Discussion

Test 1 related with a general inspection of the equipment fulfills all the requirements. Three equipments are in and overall excellent conditions both mechanical, electrical and signs. Test 2 gave a low mean values in all the three equipments, this result does not represent any risk in the controlled area and the public as well. As it can be seen in table 1, at the controlled area the values are below 0.1 mSv/sem. and 0.01 mSv/sem. in public area. During the measurement of the Leakage radiation, collimators did not close completely, for this reason it was necessary put over the tube 0.5 mm Lead plaque in order to ensure the total obstruction of the beam. In the Aristos equipment it was obtained a value of 1.14 mGy/h, which is over the limit 1.0 mGy/hr. This was the only date out of the reference level. The other values agree with the reference levels, as it can be seen in figure 3. Concerning to test 4, the three equipments succeeded due to the peak of the cone was inside the circle in the Pro-Digi Phantom. Then, it can be said that the beam is perpendicular to the image receptor. For test 5 the tolerance level must be below 2%, table 2 shows ROIs and its differences having a good result. In the accuracy of the nominal value of the voltage, all the data belong in the 10 % tolerance limit. For example, in the figure 5 for 80 kV the accuracy succeeded. This parameter ensures a correct exposition of the patient and the health staff as well. The Half Value Layer in test 6, table 4 resumes all the measured values. It was got high values in all the kV range for thickness between 1.15 and 3.15 mm. The outcome of this test verifies the viability of the beam filtration and it corroborates that the beam has the enough strength to pierce for example a chest. The dose percentages in the repeatability test are low and the dose keeps constant for each try as it can be seen in table 5. Also, it was got performance values in the system below 50 uGy/mAs as it is shown in table 6. Figure 4 is an indicator of the effectiveness of the equipment in each kV. Both the accuracy and the repeatability of the exposure time are acceptable conditions. As it can be seen in figure 5, the measurements of the exposure time give a minimum error value; besides, table 6 exhibits the repeatability so below the tolerance Related with the AEC has an acceptable state in two equipments. As it is seen in Figure 5, with a typical skull sample in the Aristos equipment shows an extra exposition when it is not necessary. It was found out some failures both Multix and Aristos in the performance AEC tests; on cause could have been non-calibration sensors or a non-upgrade of the software. On the other hand, grilles tests fare well. Let us move to the quality images tests. Figure 7 reflects that it is easily seen all the sharp and small in the Pro-Digi phantom; making a zoom is observed a special resolution of 3.7 LP/mm, this is a high
resolution having present the parameters of acquisition of this test. It is also possible to distinguish the seven gray scales and an increase in the pixel number from dark region to light region, which ensures a high fidelity in the dynamic range. On the other side, all the structures in the phantom are clearly differentiated with 1.2 % in contrast. Related with geometric distortion and size of field it was accurately measured the using MicroDicom software showing a correspondence between both sizes; the test fare well in the three equipments. In the signal-noise relation test, table 7 shows that all the data belong 20% and it is easily seen a high number of pixels having present the small ROIs. Strange artifacts were not found in all the tests made. The background noise test gave a low DAP with a fair definition (see table 8). As it is seen in figure 7 the noise is minimum with chest standard acquisition parameters, indeed it is verified the signal-noise relation through table 8 where is very low and confident. In order to evaluate the calibration of the system, it was taken the dose values from table 5 and compared with those shown by the system; this comparison exhibited an error around 0.23 %. In that way, it was measured DAP values with the Geiger counter instrument in a range from 5.57 to 2574.7 uGy*m² in 65 standard radiographic tests with an error of 0.17%. This exhibits successful tests and the adequate conditions of the dose measurement system of the equipments. As it is seen in table 9, the values of the last test belong in the reference level.

5. Conclusions
This work allowed us to evaluate the conditions in which the digital radiography equipment is located in FVL, establishing the fundamental tests from the ARCAL and the radiodiagnostic protocol of the SEFM, this was essential since it allowed us to lay the foundations of a program quality control for digital radiography equipment, and empowers us to design in the near future our own quality control tests that allow us to give a more accurate assessment and a more effective solution to the failures that may occur, thus contributing in everything related to radiological protection and quality control in equipment emitting ionizing radiation.

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