

THE RELEVANCE OF QUALITY CONTROL IN SERVICES OF HEMODYNAMICS AND INTERVENTIONAL CARDIOLOGY*

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Abstract **OBJECTIVE:** To evaluate the performance and quality of images of a x-ray equipment utilized in interventional radiology, by means of some tests of quality control. **MATERIALS AND METHODS:** Measurements have been performed on a Philips Integris H3000 x-ray equipment dedicated to interventional procedures in the hemodynamics laboratory of a hospital in Rio de Janeiro, RJ, Brazil. Leeds test objects have been used to evaluate the image quality. Dosimetric measurements have been developed with a Radcal 9015 dosimetric system. **RESULTS:** In high and normal modes, the air kerma rates have been different from the expected results. In some cases, values have not been affected by the use of different magnification modes. The images quality evaluation has showed different results from those recommended by technical standards. This could lead to the acquisition of poor quality images besides an increase in the radiation exposure levels for both patients and staff. **CONCLUSION:** The results have shown the importance of a periodical quality control testing, allowing the monitoring of the x-ray equipment performance and evaluation of radiation exposure levels for both patients and staff. The results suggest the need of a revision of the x-ray images acquisition system. *Keywords:* Interventional radiology; Hemodynamics; Quality control.

Resumo *A importância do controle de qualidade em serviços de hemodinâmica e cardiologia intervencionista.* **OBJETIVO:** Avaliar o desempenho de um equipamento de raios X utilizado em radiologia intervencionista e a qualidade de imagem produzida, aplicando alguns testes de controle de qualidade. **MATERIAIS E MÉTODOS:** O equipamento de raios X testado foi da marca Philips (Integris H3000), do serviço de hemodinâmica de um hospital do Rio de Janeiro. Foram utilizados objetos de teste de Leeds para avaliar a qualidade da imagem, e um sistema Radcal 9015 para medições dosimétricas. **RESULTADOS:** Nos modos *high e normal*, os valores medidos das taxas de kerma no ar foram diferentes dos esperados. Em alguns casos, os valores das taxas medidas não foram afetados pelo uso de diferentes modos de magnificação. A avaliação da qualidade da imagem apresentou resultados diferentes dos valores recomendados pelas normas. Isto pode levar à obtenção de imagens de menor qualidade e ao aumento da exposição à radiação de pacientes e profissionais. **CONCLUSÃO:** Os resultados mostraram a importância da aplicação periódica de testes de controle de qualidade, que permitem monitorar o desempenho do equipamento e estimar a exposição dos pacientes e trabalhadores. Os resultados obtidos sugerem a necessidade de uma revisão no sistema de aquisição de imagens do equipamento.

Unitermos: Radiologia intervencionista; Hemodinâmica; Controle de qualidade.

INTRODUCTION

Interventional radiology involves diagnostic and/or therapeutical interventions guided by means of percutaneous or other access, and usually performed under local anesthesia and/or sedation, using a fluoro-

scopic image to localize a lesion or treatment site, the fluoroscopy plying the main role of monitoring the procedure, controlling and documenting the therapy⁽¹⁾. It is one of the radiodiagnosis methods which give patients highest radiation doses, and where the exposure to radiation is more critical for the practitioners. The percutaneous access is performed by means of a guided catheter inserted by the physician. The catheter insertion up to the treatment site, as well as the whole diagnostic and therapeutical procedure, is performed under fluoroscopy, whose images are displayed on monitors both inside and out of the room. Because of the need for iodine contrast injection, and their high degree of complexity, the procedures require the support of assistant

physicians, technicians and nurses to be performed. For a better visualization of the site to be investigated, it is possible to change the x-ray beam angle of incidence around the patient, sometimes increasing the level of radiation exposure for the operator and assistants near the x-ray equipment. Additionally to the relative positioning of the x-ray tube, the radiation exposure is proportional to the technique utilized during the whole procedure, and parameters like voltage (kV), amperage (mA), dosing rates, the fluoroscopy times, among others.

On the other hand, in interventional radiology, attention must be paid to the imaging quality, considering the reduced calibers and different densities of structures and tissues to be studied.

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So, the optimization of the practices in interventional radiology is a critical aspect that should not be disregarded. Quality control procedures constitute a tool in the process of optimization of the radiological protection in the practices, by means of monitoring of the different parameters influencing the equipment performance, the radiation doses both for patients and practitioners, and the images quality. The quality control allows the monitoring and maintenance of the quality necessary for diagnostic or therapeutical purposes of the interventional procedures in question^(2,3). The Brazilian legislation concerning radiological protections in radiodiagnosis — Ministry of Health Order (Portaria) no. 453/98⁽⁴⁾ — establishes few requirements regarding quality control in interventional radiology. In April of 2003, the Agência Nacional de Vigilância Sanitária (National Agency for Sanitary Vigilance) published the Resolution no. 64⁽⁵⁾ with some recommendations about procedures of quality control for diagnostic services, including some tests in fluoroscopy. Performing periodical testing is not a routine practice in the Brazilian hospitals yet.

The objective of the present study was to evaluate the performance of a x-ray equipment utilized in interventional radiology, applying some quality control tests.

MATERIALS AND METHODS

The present study has been developed in a Philips Integris H3000 model fluoroscopic equipment (Figure 1) installed in a hemodynamics service of a large hospital in Rio de Janeiro, RJ, Brazil. The equipment operates in the following modes: continuous low and normal, and pulsed high, 13 cm, 18 cm and 23 cm magnification modes (also called lens or zoom mode), digital cine image acquisition, and exposure control. The fluoroscopy modes determine the dosing rates delivered by the x-ray beams. So, for a single exposure time, the high mode should deliver to the patient a higher dose than the low and normal modes. The magnification modes allow an increase in spatial resolution of images of the region to be studied. It is important to note that the lower the magnification mode, the higher the patient dose to allow a same



Figure 1. U-arc Philips H 3000 equipment utilized in interventional radiology with an image intensifier, two overhead monitors and patient table with controllers.

image quality. The values of 13 cm, 18 cm and 23 cm represent the diameter of the image intensifier input screen utilized.

In equipment evaluated in the present study, the controllers for the arc movements and distance between the x-ray tube and the images intensifier are coupled with the table. The equipment has two video monitors inside the room for visualizing the procedures (Figure 2). The video monitor at left is utilized for images freezing, while the video monitor at right displays real time image during the procedure. For the procedures optimization, the quality of the images must meet the quality criteria according to the objective to be reached.

One of the ways to estimate the radiation dose delivered to the patients is measuring the amount of energy deposited per

mass unit, denominated “air kerma”, expressed in milliGray (mGy). Due the dynamic nature of this procedure, in fluoroscopy, it is more appropriate to measure the “air kerma rate” (in units of mGy/min) than simply the air kerma.

Dosimetric tests were performed to evaluate the air kerma rate in the patient’s skin entrance, in the image intensifier input, and image quality test for evaluating high- and low-contrast spatial resolutions and distortion. Also the half-value layer (HVL) was evaluated.

Measurements of skin entrance and image intensifier input air kerma rates

The measurement of skin entrance and image intensifier input air kerma rates should be performed on an annual basis

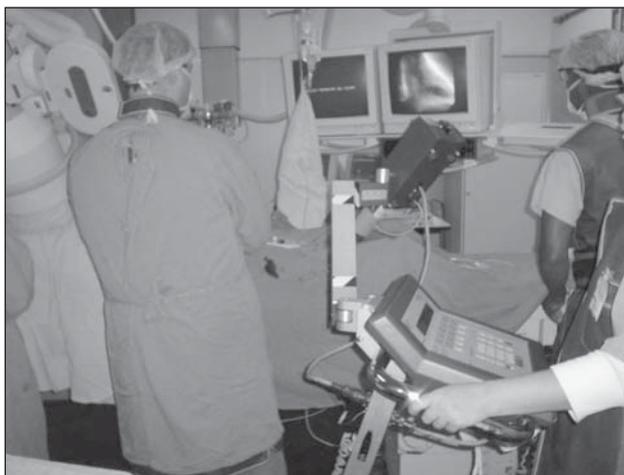


Figure 2. Equipment being operated by practitioners (physician at left, technician and nurse at right) in the hemodynamics room.

and/or after equipment repairs, under normal operational conditions. The measurement of the image intensifier input air kerma rate yields an estimate of x-ray equipment performance.

A Radcal dosimetric system consisting of a 9015 electrometer and a 10X5-60cc ionization chamber was utilized, with the ionization chamber positioned towards the x-ray beam. The reading is made by the electrometer. For simulating the presence of a patient, a 1mm-thick copper plate was utilized. The plate, as well as the patient, attenuates the x-ray beam (Figure 3). The skin entrance air kerma rate was measured for 18 cm and 23 cm magnifying modes (image intensifier diameter) which are the most utilized in procedures of this hemodynamics service. The x-ray tube was positioned at 100 cm from the image intensifier, with the ionization chamber at 30 cm from the image intensifier input, and 1 cm above the table, within the radiation field. The copper plate was placed over the ionization chamber (Figure 3).

For evaluating the image intensifier input air kerma rate, the ionization chamber was fixed in the intensifier input, and the x-ray tube was positioned at 85 cm from the image intensifier. The copper plate was

placed on the examination table for simulating the patient. Exposures were performed registering the air kerma rate in mGy/min measured by the ionization chamber in low, normal and high fluoroscopic modes, as well as the kilovoltage (kVp) and amperage utilized for 18 cm and 23 cm magnification modes (Figure 4).

Evaluation of high-contrast spatial resolution and low-contrast discrimination

The estimation of high- and low-contrast resolutions was performed with the aid of test objects developed by University of Leeds for semiquantitatively analyzing x-ray images quality^(6,7). The test objects bear details of different materials and thicknesses inside. For the testing, each test object is fixed to the image intensifier input screen. It is recommended that tests are ran at each half-year or every time the equipment is serviced.

The high-contrast spatial resolution is evaluated in terms of line pairs per millimeter (lp/mm), discriminating alternating black and white line pairs into groups of different spatial frequencies on the image displayed on the monitor screen. The low-contrast resolution is evaluated in terms of

percentage of contrast between circles of different densities (details) and their background on the image displayed on the monitor screen or image register system. Figure 5 shows the image of a Leeds TOR (TVF) test object.

For determining the high-contrast resolution of the image displayed on the monitor screen of the x-ray equipment in question, one has identified the group of line pairs where two lines can be separately identified. For determining the number of lp/mm that the images system can resolve, the Leeds test object manual includes a table of equivalences between the group identified on the image and the correspondent number of lp/mm.

The low-contrast resolution evaluation consists of the counting of visible circles (those differentiated from the background) on the image displayed on the monitor screen. For the low-contrast resolution, the Leeds test objects manual^(6,7) includes a table with the contrast degree as a function of the number of circles identified on the image, and suggests a 4% value as a lower acceptance threshold. The results were compared with those established by the order (Portaria) 453 (Table 1). However, it is important to note that the Order

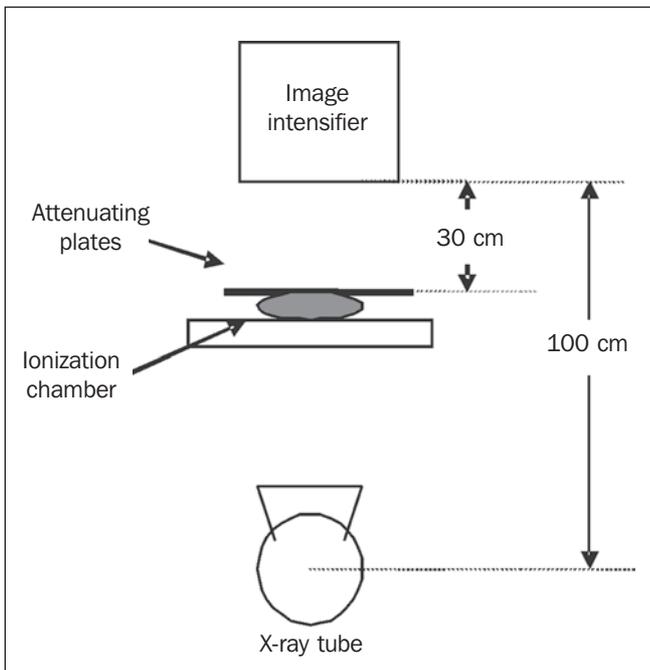


Figure 3. Positioning of an ionization chamber and attenuating plates in relation to images intensifier and x-ray tube during measurement of skin entrance air kerma rate.

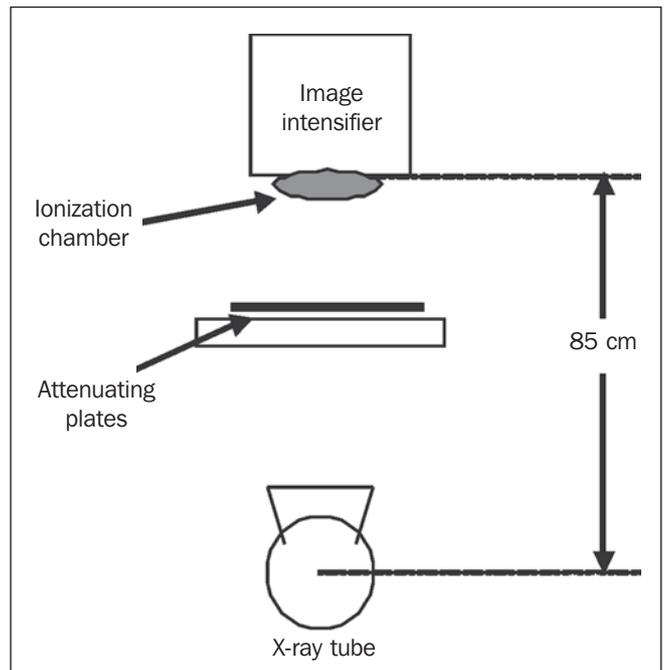


Figure 4. Positioning of ionization chamber and attenuating plates in relation to image intensifier and x-ray tube during measurement of image intensifier input air kerma rate.

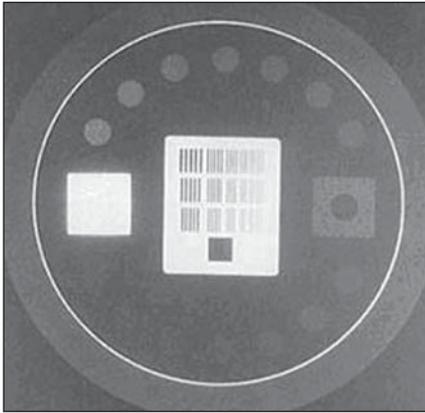


Figure 5. Image from a Leeds test object utilized to evaluate high- and low-contrast resolutions on fluoroscopic equipment monitor screens⁽⁶⁾.

(Portaria) 453/98 generalizes the recommendations for a conventional fluoroscopic system, but acceptable thresholds should be defined by the physicist-physician responsible by the quality control for each x-ray equipment, considering the equipment specific application and the requirements of each interventional technique utilized (cardiology, vascular medicine, neuroradiology, etc.).

Distortion

This test is aimed at determining whether the imaging system introduces geometrical distortion on images displayed on the available monitor screens. In case this distortion exists, the Leeds TO M1 test object allows the quantification of the distortion degree. If the distortion is significant, the image on the monitor screen, mainly the internal monitor in the hemodynamics room, may lead to misinterpretation during the procedure. The Leeds TO M1 is a wire grid (radiopaque material) test object that allows the observation of a square matrix image on the monitor (Figure 6), where the distances between vertical and horizontal lines are uniform and known.

The distortion on the internal monitor of the hemodynamics room was evaluated. The test was performed with the test object fixed to the images intensifier input screen so that the central square was positioned closer to the irradiation center. On an image without geometric distortion, all the squares should present the same dimensions, corresponding to perfect squares. The evaluation is aimed at identifying the

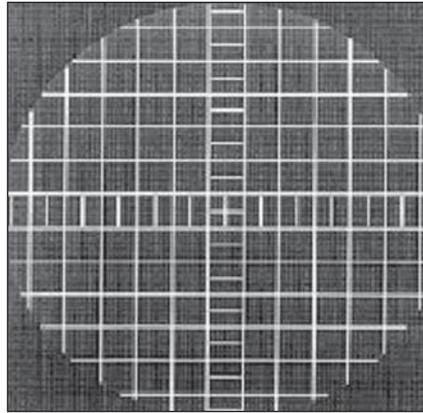


Figure 6. Image from a Leeds test object utilized to evaluate distortion on fluoroscopic equipment monitor screens⁽⁶⁾.

largest visible square matrix ($n \times n$ squares) on the image. Then, the main and secondary diagonals of the largest square matrix were measured with a ruler, as well as those of the squares in the center and extreme points of the matrix (lower left and right, and upper left and right). A square region (seven squares on the horizontal plane, and seven on the vertical plane) was evaluated. The distortion was calculated in the region where the diagonals of the extreme points squares are larger in length. Based on the measured values, the image distortion on the monitor was determined by means of equation 1:

$$Distortion = \left(\frac{D_m}{D_c \times n} - 1 \right) \times 100\%$$

Equation 1. Equation for determining the image distortion degree on the monitor screen⁽⁷⁾.

where: D_c is the central square diagonal; n is the number of complete squares utilized for representing the diagonal of the region with higher distortion; and D_m is the sum of the squares diagonals of the diagonal with higher distortion.

Half-value layer evaluation

HVL is defined as the aluminum (or equivalent material) filter thickness that must be placed on the x-ray beam output port to reduce the intensity at half. The HVL is an essential parameter for characterizing the beam quality, and based on this value, it is possible to determine the total x-ray tube filtration. As already known, aluminum (Al) filters are placed to attenuate

low-energy photons which do not contribute to the images formation, but rather to the dose delivered to the patient. The minimum total filtration of a diagnostic x-ray equipment must have is at least 2.5 mmAl⁽⁴⁾. The objective of the HVL measurement is to evaluate whether the x-ray tube has an adequate filtration. This test must be performed once a year and after repairs⁽⁴⁾.

The device utilized in this test was a Radcal 10X5-60 ionization chamber coupled with an electrometer, Al filters and a tape measure. The measurements were performed for an 18 cm magnification in the normal scopy mode. The ionization chamber was positioned above the table, under the x-ray beam, at a 45 cm distance from the focal point. The distance between the focal point and the image intensifier was 101 cm. The Al filters were placed between the ionization chamber and the image intensifier up to achieving a tube voltage near 50 kVp. Aiming at keeping a constant irradiated thickness, all the filters remained positioned towards the x-ray beam during this test for not modifying the automatic exposure control settings. The first exposure was performed with the filters positioned between the chamber and the images intensifier (non-attenuated beam). During the test, the filters were displaced one by one, between the x-ray tube and the ionization chamber (attenuated beam). For each displacement 1 min exposures were performed, and the air kerma rate measured. This procedure was repeated up to a value lower than half the value of the first reading was achieved. The HVL value was found by means of equation 2:

$$CSR = \frac{x_b \ln\left(2 \frac{L_a}{L_0}\right) - x_a \ln\left(2 \frac{L_b}{L_0}\right)}{\ln\left(\frac{L_a}{L_b}\right)}$$

Equation 2. Equation for determining the half-value layer of the x-ray equipment⁽⁶⁾.

where: L_0 is the average of the initial exposure readings; L_a is the exposure reading immediately superior to $L_0/2$; L_b is the exposure reading immediately inferior to $L_0/2$; X_a is the Al thickness corresponding to the L_a reading; X_b is the Al thickness corresponding to the L_b reading.

Aiming at knowing the HVL value for 50kVp, an interpolation was performed with basis on the HVL table included in the Order (Portaria) 453/98⁽⁴⁾.

RESULTS AND DISCUSSION

Measurement of skin entrance and image intensifier input air kerma rate

The results of the measurements of skin entrance and image intensifier input air kerma rates performed in the x-ray equipment utilized in the present study are included in Table 1. The skin entrance air kerma rate resulted lower than those established by Order (Portaria) 453/98⁽⁴⁾.

In the present study, the skin entrance and image intensifier input air kerma rates measured in high mode were lower than those in the normal mode, although the reverse result was expected. However, we have observed that while in the high mode the beam is pulsed, in the normal mode the fluoroscopy is continuous. The pulsed fluoroscopy contributes for minimizing the exposure, but the diagnostic image quality is lower. Typically, in the high mode, the air kerma rate is high, allowing a better images quality, a feature some times required by the interventional procedure, when better resolution and contrast of certain regions are necessary. This characteristic was not observed in the measured skin entrance air kerma rates, a fact suggesting that the air kerma rate in the high mode was changed in the x-ray equipment, probably to reduce the dose delivered to the patient. So, the utilization of the high mode has lost its function.

Both for the high and normal modes, a magnification variation (from 18 cm to 23 cm) did not present a significant influence on the rates measured, within the uncertainties associated with the measurements.

The air kerma rate also is high during the utilization of the equipment in the images acquisition (cine) mode, as a function of the need for high quality images.

Evaluation of the high-contrast spatial resolution, low-contrast discrimination, and distortion

The tests results for high-contrast resolution are shown on Table 2. Aiming at guaranteeing a good diagnosis in inter-

Table 1 Results of measurements performed to evaluate image intensifier input and skin entrance air kerma rates.

Mode	Magnification	Image intensifier input air kerma rate			Patient's skin entrance air kerma rate		
		kV	mA	µGy/min	kV	mA	mGy/min
Low	18	—	—	—	47	0.7	2.1 ± 0.1
	23	—	—	—	45	0.6	2.8 ± 0.1
Normal	18	49	7.5	1.89 ± 0.09	40	7.5	13.9 ± 0.7
	23	47	7.5	1.24 ± 0.06	40	7.5	14.2 ± 0.7
High	18	53	4.5	1.63 ± 0.08	44	4.5	9.2 ± 0.5
	23	50	4.5	1.10 ± 0.05	41	4.5	8.5 ± 0.4
Cine	23	55	500	6.11 ± 0.30	50	500	49.4 ± 2.5

Table 2 Result of tests to evaluate high- and low-contrast resolution.

Mode	Magnification	Resolution			
		High contrast		Low contrast	
		Internal monitor (p/mm)	External monitor (p/mm)	Internal monitor (%)	External monitor (%)
Low	18	1.12	1.25	1.8	1.8
Normal	18	1.25	1.64	1.8	2.7
High	18	1.25	1.51	1.8	1.8
Cine	18	1.25	1.00	2.3	3.9

ventional radiology procedures performed in hemodynamics services, a high-contrast resolution is necessary to identify arteries, veins and lesions to be investigated, mainly for coronary procedures where the investigated and treated structures present low caliber. The Order (Portaria) 453/98⁽⁴⁾ recommends a high-contrast resolution value expressed in lp/mm > 1.4 lp/mm for the 15–18 cm magnification mode, and = 1.0 lp/mm for the 23–25 cm magnification mode. However, the values found in this test, on the internal hemodynamics room monitor, resulted lower than the recommended ones. This suggests that there may be anatomical details of difficult visualization on images observed on the monitor screen, inducing the physician to submit the patient to longer exposure times for acquisition of a higher number of images.

On Tables 1 and 2, it is possible to observe that, in spite of the skin entrance air kerma rate being higher in the normal mode than in the high mode, there was no improvement in the image quality (high- and low-contrast resolutions) on the internal monitor.

For low-contrast, a resolution between 1% and 4% is recommended^(1,4-7). The val-

ues found by the present study present an acceptable low-contrast resolution, according to Table 2.

Generally, the external monitor presented a higher quality than the internal one. It is important to note that the image quality is strictly related to the final medical-diagnostic objective of the procedure.

In the distortion test, the evaluated monitor presented 5.1% distortion, lower than the 10% value recommended by the Leeds test objects manual⁽⁷⁾. The results of the measurements are shown on Table 3, and calculations were made for the main diagonal, and with the squares of the left upper and right lower corners, employing the equation 1.

Table 3 Dimensions measured during test for evaluating the image distortion degree.

Localization of the square	Diagonal (cm)
Left lower corner	4.4 ± 0.3
Left upper corner	4.5 ± 0.3
Central	4.2 ± 0.3
Right lower corner	4.7 ± 0.3
Right upper corner	4.7 ± 0.3
Main diagonal	30.9 ± 0.3
Secondary diagonal	30.7 ± 0.3

Half-value layer

Values found in the HVL evaluation are shown on Table 4. The value resulting from the HVL calculated by means of equation 2 was 2.0 ± 0.1 mmAl, for a 50 kV voltage, with a reference value of 1.7 mmAl⁽⁴⁾. For this value of HVL and voltage, the total filtration of this equipment resulted in 3.5 mmAl⁽⁸⁾. The useful beam HVL value should not be lower than 2.5 mmAl.

CONCLUSIONS

The results of the present study regarding dosimetric measurements (skin entrance and image intensifier input air kerma rates) demonstrated the relevance of a periodical evaluation by means of quality control tests, allowing the monitoring of the equipment performance, detection of anomalies or operational problems, as well as an estimation of workers and patients radiation exposure levels.

In the same way, the results regarding images quality suggest the necessity of a review of the images acquisition system of the fluoroscopic equipment. The periodical testing provides concrete data which can lead to an improvement in the image quality, since these data allow the identification

Table 4 Results of the measurements performed for determining half-value layer.

Thickness (mmAl)	Reading (mGy/min)
0	11.1 ± 0.6
2	5.6 ± 0.3
3	4.2 ± 0.2
5	2.5 ± 0.1

of possible degradation of the imaging system along time. This evaluation is particularly significant on the monitor screen localized inside the examination room, which is indispensable for the dynamic and real-time follow-up of the procedure.

The quality control is a tool in the implementation of radiological protection measures for every individual involved in interventional procedures, as well as other measures associated with priority aspects of equipment maintenance and achievement of an image quality sufficient to reach the required diagnostic results.

The physicist-physician interaction with the medical professionals is essential for him to interpret his necessities allowing a safe work and accurate diagnosis. The consciousness of physicians and technicians on this aspect is extremely important, as well as an adequate training of every pro-

fessional involved in interventional radiology procedures.

This is part of the work developed by the physicist-physician of the service, who must effectively participate in the specialists staff of a hospital, according to requirements of the Brazilian legislation and good practices recommendations associated with radiation.

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