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Evaluation of Display Performance for Medical Imaging Systems in the cities Salvador (BA) and Florianópolis (SC)

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ABSTRACT

The objective of this study was to evaluate the performance of medical imaging systems in the city of Salvador (BA) and Florianópolis (SC). Materials and methods: were evaluated 15 display devices which are used to diagnose in 5 health institutions, according to the methods described in AAPM report 03 and the Spanish protocol. Were verified 9 parameters, comprising 13 tests (quantitative and qualitative) and grouping a total of 29 compliance criteria for each display device analyzed. The instrumentation used in the execution of the tests has traceability to RBC and NIST. Results and discussion: characterization of the sample indicated that 6 display devices were not indicated by the manufacturer for such use, and one of them is of the commercial display device type. The parameters that presented the best and the worst results were respectively, geometric distortion with 100% and luminance dependence with 0% of compliance. The commercial display device was the only display device in the sample that did not conform to the resolution and veiling glare parameters, also showed a significant deviation of 76% from the contrast response of the DICOM GSFD standard. Results of geometric distortion, resolution, veiling glare and noise tests corroborate with other studies and indicate that the current technologies used for medical display devices (LCD and LED) optimize their performance for these parameters. Conclusions: There are nonspecific display devices for diagnosis being used for these purposes and the display devices declared by the manufacturers as diagnostic specific on average showed a higher compliance rate.

Keywords: evaluation, performance, diagnostics display devices.

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1. INTRODUCTION

Despite the existence of protocols and standards for the evaluation of the quality of medical imaging systems, such as Report 03 of the American Association of Physicists in Medicine (AAPM) Task Group (TG) 18 [1], Spanish Protocol for Quality Control in Radiodiagnosis [2], IEC 62563-1 among others, in Brazil, only the state of Santa Catarina, has the normative resolution that required evaluation of display devices used in the practice of radiodiagnosis.

No data were found regarding the population of medical display devices. However, according to the latest survey conducted in 2012 of the National Health Facilities of the Ministry of Health, in Brazil there were 73,386 equipment in the country, among them mammography (MM), computer tomography (CT), Magnetic Resonance Imaging (MRI) and X rays machines, which can potentially be associated with the use of medical display devices, 4410 of which are in Bahia and 3155 in Santa Catarina.

Although there is no direct relationship between the number of these devices and the number of diagnostic display devices used, it is worth mentioning that with the advancement of digital technology and the increase of the practice of teleradiology in Brazil, the use of display devices is increasing.

According to the criteria of the Food and Drug Administration (FDA), American College of Radiology (ACR) and Report 03 of the AAPM [1], display devices may be classified as "primary display devices" or "diagnostic display devices" and "secondary display devices" or "clinical display devices". Diagnostic display devices are those that are intended for the interpretation of radiological images, while "secondary display devices" or "clinical display devices" are intended for the visualization of images in general, which is not intended for medical interpretation. This division allows differentiating both the technical characteristics required of the display devices and the criteria of acceptability in the performance tests.

Regarding the technical characteristics of the display devices in Brazil, Ministerial Order No. 2.898 of November 28, 2013 of the Ministry of Health [3] as well as the Resolution of the Federal Council of Medicine (CFM) No. 2.107/2014 [4], only presents requirement for the use of a specific display device for digital mammography, leaving no technical detail on the subject. Therefore, as it

is not known the reality in the country regarding the safety and image quality exhibited by this equipment's, it is necessary to evaluate the performance of the medical image display devices that are being used for diagnoses, to avoid erroneous and all associated problems.

2. MATERIALS AND METHODS

A study was carried out to evaluate the performance of the display devices used for the diagnosis of radiological images in Salvador (BA) and Florianópolis (SC), Brazil, in the year 2016, using the procedures described in American Association of Physicists in Medicine AAPM Task Group (TG 18) and Spanish Protocol for Quality Control in Radiodiagnosis, 9 fundamental parameters for image quality were evaluated, comprising 13 tests (quantitative and qualitative) and grouping a total of 29 compliance criteria for each display device analyzed, which are summarized in table 1.

In this study, 15 display devices that are being used for diagnoses in 5 health institutions were evaluated by means of convenience sampling, according to the availability and interest of the institutions, being 3 in the city of Salvador (BA) and 2 in Florianópolis (SC).

These display devices were used in health institutions for the exposure of radiological images, acquired by various equipment, with the purpose of performing diagnoses and for that reason were evaluated according to their use. In this way, the specific requirements for diagnostic display devices were applied to all display devices regardless of the display device rating that is declared by the manufacturer.

The display devices evaluated were characterized by indication of use of the display device declared by the manufacturer, technical characteristics (lighting technology and resolution) and diagnostic modality in which it was being used by the institution.

Before the evaluations, the screen was cleaned, and the electronic stabilization time of the display devices was ensured for 30 minutes. All evaluations were carried out during low or non-working hours of the services, to avoid precipitation, and the measuring instruments were mounted with the aid of fasteners to avoid movement of the meters at the time of measurement.

Table 1: Summary of parameters and their evaluated compliance criteria

Parameters	Used tools	Compliance criteria
General aspects of the image [1]	TG18-CQ	No defective pixels, artifacts, distortions or loss of contrast in standard image preview.
Geometric distortion [1,2]	TG18-CQ Caliper rule	Edges have straight horizontal and vertical lines and centralized image presentation of the pattern ; Distortion ≤2% for diagnostic.
Screen reflection and Room lighting [1,2]	TG18-AD Photometer	There should be no difference in contrast perception of the standard image; The observer should not detect the presence of light sources; The ambient illumination should be less than: 25 lx x-ray images, 15 lx for mammography and 60 lx for the other modalities.
Luminance Response [1,2]	TG18-TC TG18-MP TG18-LN Photometer	The display of the standard image should demonstrate the low contrast targets in each of the regions 16 ;L(máx) ≥ 170 cd/m²; Luminance Ratio ≥ 250; Luminance variation between display devices of the same station ≤ 10% and ≤ 5% for mammography; Deviation of DICOM contrast response GSDF ≤ 10%
Luminance Dependency [1,2]	TG18-UNL TG18-TC TG18-LN	The pattern should be free of non-uniformities from the center to the edges; there should be no luminance variations with dimensions on the order of 1 cm; the viewing angles should be established; not the uniformity of the luminance should be <0.3.
Resolution [1]	TG18-CQ Magnifying glass	Line pairs patterns should be visually distinguishable; horizontal and vertical lines should be noticeable in all places; the CX score should be between 0 and 4; the 16 steps of the gray scale should be visually distinguishable.
Noise [1]	TG18-AFC	Contrast objects should be visible in at least 3 quadrants
Veiling Glare [1]	TG18-GV Mask	At least three contrast objects should be displayed by standard images
Chromaticity [1]	TG18-UN	All station screens must have color uniformity.

Legend: [1] Qualitative test; [2] Quantitative test

When the display devices allowed manual adjustment of brightness, the procedure described in subsection 3.4.5 was used. of the AAPM report 03. All standard images viewed on the display devices evaluated were in 16-bit Digital Imaging and Communications in Medicine (DICOM) format and windowing adjusted for: Window Width (WW) = 4096 and Window Level (WL) = 2048 except for standard TG18-LN images, and TG18-AFC which were displayed with WW of 4080 and WL of 2040, as indicated in the procedure.

In the quantitative evaluations, the luminance and illuminance measurements were performed with the Gossen photometer, Mavolux 5032B USB, serial number 0C21580 with calibration traceable to the Brazilian Calibration Network (RBC) for illuminance magnitude and the National Institute of Standards and Technology (NIST) for the luminance magnitude. This equipment has automatic scale change system and measuring range from 0.01 to 199.000 lux (for illuminance) and 0.1 to 1.999.000 cd / m² (for luminance).

For dimensional measurements, the Starret caliper was used, serial number 02/19943, with a calibration error of 0.05 mm and RBC traceability.

It is emphasized that there is no ethical implication in the research, since the works were developed only with machines and image standards. There is no human involvement. The names of the institutions and the manufacturers of the display devices on which the tests were performed were omitted, taking as reference only the quantity evaluated.

3. RESULTS AND DISCUSSION

Besides the characterization of the sample, a total of 9 parameters were evaluated, divided into 13 performance tests (qualitative and/or quantitative), which grouped a total of 29 compliance criteria for each of the 15 display devices studied, totaling, at the end of the study, 435 criteria evaluations conformity. None of the evaluated radiological display devices demonstrated complete compliance for all performance tests. To facilitate understanding, the results are presented in terms of characterization of the sample, overall performance (number of display devices that meet all the criteria of that test) and the individual compliance rate of each display device in relation to the test

criteria (the ratio of the total number of test criteria by the number of criteria on which the display device complied).

The table 2 shows that 15 display devices were evaluated, of theses, 9 are declared by the manufacturers as specific for use in diagnosis and 6 are not declared as such.

Table 2: Characterization of the display devices sample.

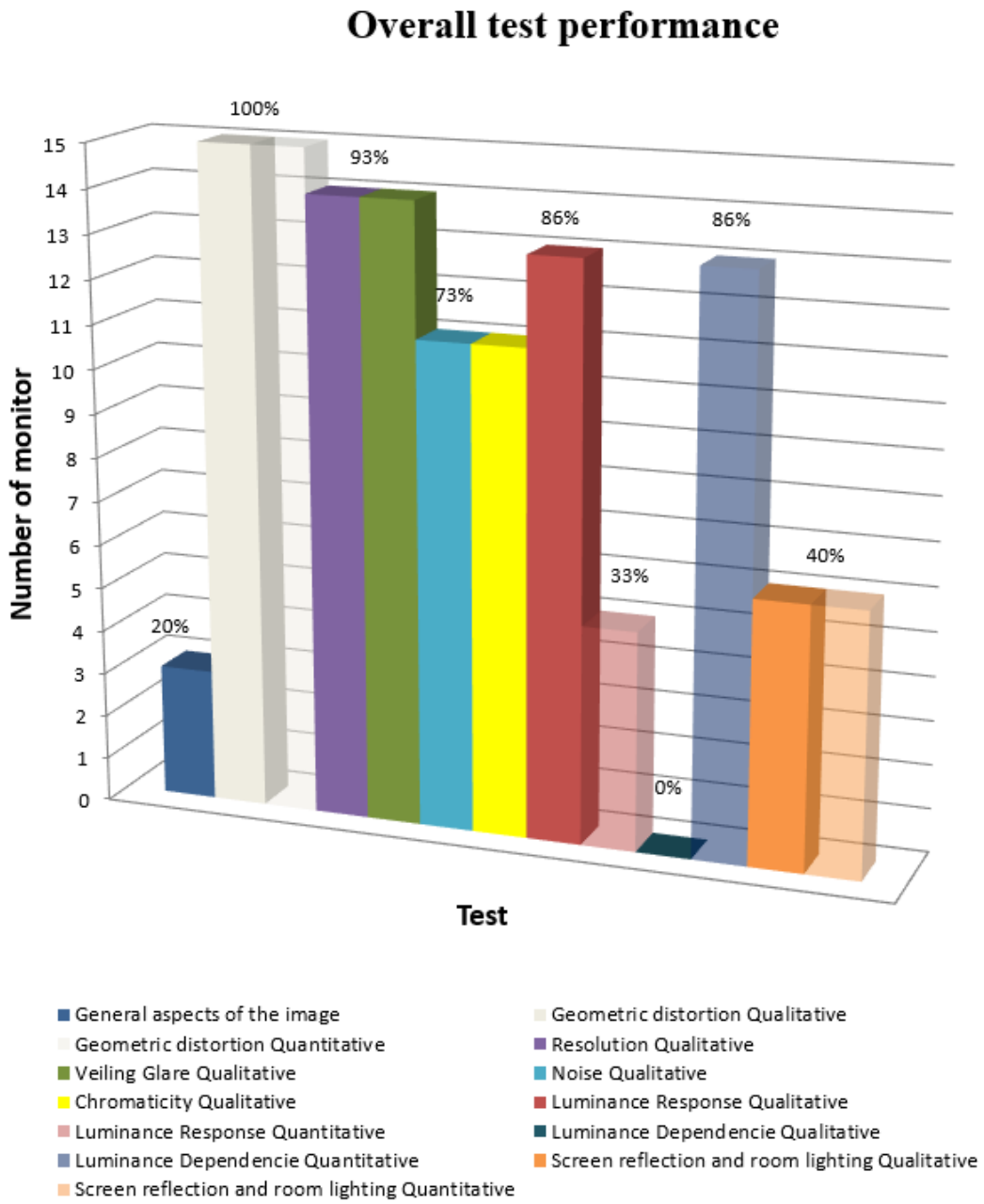
Institution	Sample number	Display device type declared by manufacturer and resolution	Diagnostic mode used by the institution
A	1	Clinical display device LCD 1 MP	CT, MRI and X-ray
	2	Clinical display device LCD 1 MP	CT, MRI and X-ray
	3	Clinical display device LCD 2 MP	CT, MRI and X-ray
	4	Clinical display device LCD 1 MP	MM, CT, MRI and X-ray
	5	Radiological display device LED 2 MP	MM, CT, MRI and X-ray
	6	Radiological display device LED 2 MP	MM, CT, MRI and X-ray
	7	Radiological display device LED 2 MP	MM, CT, MRI and X-ray
B	8	Clinical display device LCD 1 MP	CT, MRI and X-ray
	9	Radiological display device LED 3 MP	CT, MRI and X-ray
	10	Radiological display device LED 3 MP	CT, MRI and X-ray
	11	Radiological display device LCD 2 MP	CT, MRI and X-ray
C	12	Radiological display device LED 3 MP	CT, MRI and X-ray
D	13	Radiological display device LED 5 MP	MM
	14	Radiological display device LED 5 MP	MM
E	15	Commercial display device LCD 1 MP	CT, MRI and X-ray

Legend: *MP – Mega pixel.

After the characterization of the sample, it was verified that among the 6 display devices declared as non-specific, 5 were identified for clinical use and 1 for non-medical (commercial) use. The results of the sample also show that institution A and B use specific and non-specific display devices and institution E has its only display device used for diagnostic purposes, uses a commercial display device.

Figure 1 presents the graph of the overall performance and the parameters that presented the best and the worst result were: geometric distortions with 100% of conformity for the qualitative and quantitative tests and 0% of conformity for the qualitative test of the dependence of the luminance.

Figure 1: *Overall performance of the display devices in the tests*



Source: search data

The parameter "general aspects of the image" has a fast and routine test that verifies, superficially, several characteristics of the image quality. Ideally it, should be performed daily before the beginning of the diagnostic, since it allows the identification of problems of image quality before the examinations. Defective pixels and artifacts, for example, may interfere with the visualization of anatomical images, which may lead to misdiagnoses. The results show 20% of the display devices that showed total compliance with all test criteria. It was observed that the display devices that were not fully compliant with the test had low contrast display problems because they could not display all the letters that are in the TG-18QC standard image.

This result is important because the daily use of this rapid test may indicate, even superficially, a low contrast resolution problem that is an important feature in the radiological image quality, since it allows the ability to differentiate anatomical structures of similar contrast. The daily evaluation of the general aspects of the image before the beginning of the diagnostic routine is important, since it allows the identification of problems of image quality before the examinations. Defective pixels and artifacts, for example, may interfere with the visualization of anatomical images, which may lead to misdiagnoses.

The results of the geometric distortion, resolution, veiling glare and noise tests corroborate with other studies [5,6] and indicate that the current technologies used for medical display devices (LCD and LED) optimize their performance for these parameters.

Geometric distortions arise from deformities that cause the displayed image to be geometrically different from the original image. The practical consequences of such distortions affect the relative sizes and shapes of the displayed image, especially for large screens or large deflection angles. For example, a display device that exhibits concave distortion presents a hyperinflation-appearing chest image and a convex distortion display device shows a chest image with a morphology aspect in a bell [7].

Systems developed with adequate spatial resolution are required to ensure that spatial details of interest are preserved when an image is displayed on a medical display device. Systems developed with low contrast resolution, suitable, allow differentiating anatomical structures of similar contrast, such as liver, spleen and the white and gray matter of the brain. Display devices with insufficient resolution may compromise the accuracy of diagnostic interpretation of very subtle cancers such as those diagnosed in mammography [7].

The human eye has characteristics to adapt to luminous glare, better than most optical systems and it is able to perceive objects of low contrast in dark regions, even if surrounded by brilliant images. In this way medical display devices that have less veiling glare, are necessary to present good contrast in the dark regions of images with very brightness [1]. A display device with high veiling glare generates loss of contrast in the dark regions of the image, this effect is particularly significant when contrast inversion filters are used in the images. For example, images that present very slight radiological findings such as those of chest x-ray and mammography when associated with the contrast inversion filter may present significant loss of radiological information necessary for accurate diagnosis.

The chromaticity of the screen presented a 73% conformity rate to the compliance criteria. In this test it was verified that all display devices screens belonging to the same workstation had the same color uniformity. Color matching was required as an important acceptability factor in the PACS system [1]. In a color screen, the LUT (the grayscale calibration function) distributes the color range, and this allows to highlight some aspects contained in the image, for example, physiological activities. Both the luminance and chromaticity intervals must be mapped to the correct accuracy, or there may be contours in the images, distortion of the corners of objects or loss of information for physiological images. For example, PET-CT images make it possible to evaluate the metabolism of the analyzed structures. Especially in oncology the level of staging of several types of neoplasia, the intensity and distribution of the colors presented on the screen can be associated. More accurate diagnoses can modify clinical behavior, depending on the type of cancer.

Table 3 summarizes the results in the quantitative tests of the display devices evaluated. The conformance criteria in which the display devices presented the lowest and the highest number of display devices in compliance were, respectively, room illuminance and luminance variation between display devices of the same station with 6 display devices in compliance, and that of the luminance ratio and the percentage of distortion with 15.

The result for luminance response is important data, since this test indicating the main technical characteristics related to the brightness of the screen, as if the maximum luminance of the display device is enough for the display of medical images, if the contrast level is according to the DICOM GSDF standard, the relationship between $L_{(máx)}$ and $L_{(min)}$ and the luminance variation between workstations. Luminance can influence the visibility of subtle objects and the decision of experts on

the malignancy of the finding. Changes in radiological imaging patterns eventually considered irrelevant may mask an important clinical finding [8]. In addition, with brighter screens it is easier to identify more subtle details. Even when contrast is standardized for a given value, contrast perception improves with higher luminance values [9].

Table 3: Summary of the quantitative results on the display devices evaluated

Test	Criterion	Number of compliant display devices	Reference value	Mean value of the sample	Standard deviation
Geometric distortion	Distortion	15	<2,0%	0,3%	0,4%
Screen reflection and ambient illumination	Room illuminance	6	<15,0 lux[1] <25,0 lux[2] <60,0 lux[3]	22,4 lux[1] 50,1 lux[2] *	22,2 lux[1] 65,3 lux[2] *
Luminance response	$L_{máx}$	13	>170 cd/m²	317 cd/m²	176 cd/m²
	Luminance Ratio	15	≥ 250	1003	340
	Deviation of DICOM GSDF contrast response	7	≤ 10%	13,6%	7,2%
	Luminance variation between display devices of the same station	6	≤5% [1] ≤10% [2,3]	11% [1] 5,6% [2,3]	8,2% [1] 4,2%[2,3]
Luminance dependency	Non-luminance uniformity on display device	13	<30%	13,8%	14,3%

[1] Reference value when used to displaying Mammography
[2] Reference value when used for displaying X-ray
[3] Reference value when used for displaying Tomography, Nuclear Medicine and Magnetic Resonance

In the luminance dependence quality test, the absence of markings with the identification of the viewing angles of the images suggests that, at least for this parameter, the display devices evaluated did not undergo an acceptance test, since these angles should have been established in the baseline

of the equipment acceptance test. As the contrast varies according to the viewing angle, the viewing ability of the viewer varies according to the angle. A visualization of a decentralized image on a display device with high angular dependence distorts the perception of image contrast and enhances the bone rather than the pulmonary structure [7].

In the results for screen reflection and ambient illumination, in general, the non-conforming display devices showed reflections of points or light sources on the screen and illuminance values considerably higher than the recommended value, which caused a high standard deviation (65,3 lux) in the sample mean, indicating that possibly these display devices were not installed in a suitable location and/or that the specifics required for a report room were not considered in the calculation of the ambient lighting. This compliance rate could be improved by simple actions such as changes in the location where the display device was installed and/or correction of interpretation room lighting.

Ideally, the luminance distribution of the display device screen should only be associated with the light generated by the device. However, in practice, the room's ambient light (illuminance) reflects on the device's screen and adds extra brightness to the displayed image resulting in loss of contrast in the image and consequently loss of radiological information. Thus, the performance of a system of visualization of radiological images is dependent on the reflection characteristics of the display device and the illuminance of the room [1]. It is worth mentioning that the control of ambient light conditions also allows a more effective visual adaptation of the observer to interpret medical.

Other findings, although the screen cleaning condition is not a parameter of performance for the display devices, the excessive amount of dirt found may influence the clarity of the visualization of the images by the radiologist, and suggests that, at least for the institutions that participated in this study, the current internal procedures for the cleaning of radiological display devices do not exist or are inadequate.

The intention to use determines the classification among the types of display devices. In this study, all visualization devices were evaluated according to the diagnostic display criteria, since all of them were intended for this purpose.

Table 4 shows the result of the individual compliance rate of each display device and the type compliance average.

Table 4: Individual display device compliance rate and type declared by manufacturers.

Parameters and total of evaluated criteria	**Identification of the display device**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
	Number of compliant criteria														
General aspects (6)	4	4	6	5	5	5	5	6	6	5	5	5	5	5	5
Geometric distortion (2)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Screen reflection and room lighting (3)	1	1	0	1	1	1	1	3	3	3	3	0	3	3	0
Luminance response (6)	4	3	6	4	4	4	4	6	5	5	6	5	6	6	3
Luminance dependency (4)	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3
Resolution (5)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4
Noise (1)	1	1	1	1	1	1	1	0	1	1	1	0	1	0	0
Veiling glare (1)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Chromaticity (1)	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1
Display device Compliance	66 %	62 %	86 %	79 %	79 %	79 %	79 %	93 %	90 %	86 %	90 %	72 %	93 %	90 %	62 %
Type compliance	Diagnostic display device = 84%				Clinical display device = 77%						Commercial display device = 62%				

Table 4 shows that the display device classified by the manufacturer as diagnostic have a greater rate of conformity in relation to the other types. And considering individually, all the parameters evaluated, the display devices that presented the lowest performance were the display devices n ° 2 (clinical monitor) and the 15 (commercial monitor) with 62% of compliance rate. However, although both have the same compliance rate, monitor 15 showed a significant 76% deviation from the contrast response of the DICOM GSFD standard, which is a critical criterion for image quality, since it is directly related to ability to display low-contrast images. This was also the only display device in the sample that did not conform to the veiling glare and resolution parameters.

The accuracy of an inference of an overall performance result of the diagnostic display devices in use in the city of Salvador (BA) and Florianópolis (SC) may be limited in the present study, since this is a pilot study. A more comprehensive evaluation of the performance of these display devices could be better determined with an increase in the number of the sample, with the association with

anatomical quality control tests evaluated together with a radiologist and the data collection related to the time of use, emphasizing that time of use is not the year the display device was manufactured.

Medical imaging is typically the last stage of a medical imaging chain and it plays a critical role in that chain. For purposes of radiological protection, it is necessary to consider that an error at this stage may compromise any justification of radiation exposure to the patient. Radiological display devices that present a bad image, even though it does not represent a direct risk for radiation to the patient, can produce great damages, either by the lack of identification of a health problem, or by the visualization of a nonexistent element. In this way, it is possible to cite the existence of an indirect risk, since the damage is not produced by the equipment, but by the quality of the information generated for the medical diagnosis.

It is important to discuss that recently (January 2019) the AAPM published the updated version of the method called "AAPM report n° 270 - Display quality assurance". According to AAMP this update was necessary because the old version "pays significant attention to both cathode ray tube (CRT) displays and liquid crystal displays (LCDs), CRTs were the dominant display technology at the time" [10]. Nowadays, CRT technology is practically outdated, and with the introduction of organic light-emitting diode (OLED) displays, it was important to update the guidelines.

The new version also changes the category classification of class monitors (diagnostic displays, modality displays, clinical specialist displays and electronic health record (EHR) displays and was especially directed to the technologies of LCD and OLED displays. And it is important that new studies that aim to evaluate these display technologies use the updated method.

4. CONCLUSION

This study shows that none of the evaluated radiological display devices demonstrated complete compliance for all performance tests, display devices specified by manufacturers as non-diagnostic are used for these purposes and that there are many display devices used without routine checks of the general aspects of the image, in rooms with high illumination, high dirt on the screen and the non-implantation or inadequacy of acceptance tests and of quality control.

The display devices declared by the manufacturers as diagnostic specific on average presented a higher compliance rate than the other types and the commercial display device was the only display device in the sample that did not conform to the resolution and veiling glare parameters, also showed a significant deviation of 76% from the contrast response of the DICOM GSFD standard.

In general, the results of the geometric distortion, resolution and reflection tests indicate that the current technologies used for medical display devices (LCD and LED) optimize their performance for these parameters.

The conclusions presented here should be understood as the result of a pilot study, and these should be validated in later studies to be possible to generalize them.

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