Response of luminance meters used for radiodiagnostic applications

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Abstract. The objective of this work was to study the responses of the different luminance meters for a range of applications, with the purpose of quality control in radiodiagnosis (170 to 3500 cd/m² with white light source). Materials and methods: Were evaluated the calibration factors of 48 luminance meters, distributed in 10 different models for the point of 1000 cd/m² in 5500K. Results: The sample mean values of Piranha – 657 light probe, RaySafe - Xi and X2 and Unfors - Light-O-Meter P10 meters, presented greater accuracy (spectral sensitivity f1 ≤ 3% and total error fges ≤ 7.5%, according to the classification of DIN 5032-7 standard) and the sample of Fluke/Nuclear of Associates - 07-621 presented a difference of 34.6% in relation to the reference value with statistical significance. Conclusion: This study showed that for 48 equipments studied, the mean values of the calibration factors of 6 of the 10 models evaluated (which represents 62.4% of the total number of the sample) are convergent to the corrected reference value and/or within the range of ± 4.5% of uncertainty.

Keywords: Luminance meter, diagnostic, calibration.

1. Introduction
Photometry is now indispensable to ensure the quality of information provided on medical imaging devices, such as negatoscopes and radiological monitors. By definition, luminance is the density of visible radiation in a certain direction that reaches the observer and can be derived from a reflection of a surface, a light source or even a beam of light in space [1]. Its unit of measurement is the candela per square meter (cd/m²) or Nit and its usual calibration is according to the spectrum of the standard of the Commission Internationale de l'Eclairage (CIE), illuminant A (light source with filament of tungsten, correlated color temperature of 2856 K [2].

With the increasing use of digital radio diagnostic systems and the practice of teleradiology, the use of medical imaging devices has become an indispensable tool in medical practice. Luminance is the photometric magnitude that most closely resembles the perception of brightness by a person [1] and is directly linked to the ability of the specialist to view important radiological findings such as, for example, fibrous, calcified or neoplastic micro regions, typical of mammograms [3]. The possibility of an inadequate interpretation of a radiological examination due to inadequate luminance from medical imaging devices is a concern of several international organizations and represents a serious risk for patients [4]–[7].

In this work it was identified that currently, in Brazil, there are three standards [8]–[10] that present requirements for the measurement of luminance magnitude. These applications are for medical imaging...
devices, which basically use a light source, with a natural color temperature between 5000 K and 6000 K, and intensity of 170 a 3500 cd/m², as the name itself induces, these sources provide a naturally white illumination. One of the qualities of this color is that it does not significantly alter the perception of the coloration of the objects being illuminated or displayed.

When the user performs measurements on light sources other than the standard calibration source, illuminant A, it becomes necessary to determine the correction factor of the spectral distribution to adjust the difference in reading of the instrument as a function of the difference of spectra between the illuminant being measured and illuminant A.

In this context, a calibration in the radiodiagnosis range with the application of the correct corrections acquires basic requirement boundary to guarantee the metrological reliability. Thus, the objective of this work was to study the responses of the different luminance meters for an application range, with the purpose of quality control in radiodiagnosis.

2. Materials and methods:
By means of convenience sampling, according to the equipment availability, 48 luminance meters distributed in 10 different models were evaluated, as described in table 1. The responses of these equipment’s were evaluated through the average of the calibration factors of the samples for the point of 1000 cd/m² with source of color temperatures of 5500 K.

| Equipment                                | Quantity | Percetange of total |
|------------------------------------------|----------|---------------------|
| RTI - Piranha 657 Light probe            | 12       | 25.0%               |
| Fluke/Nuclear Associates - 07-621         | 11       | 22.9%               |
| RaySafe - Xi                              | 8        | 16.7%               |
| RaySafe - X2                              | 4        | 8.3%                |
| Unfors - Light-O-Meter P10                | 4        | 8.3%                |
| Unfors – Light-O-Meter P11                | 2        | 4.2%                |
| Gossen – Mavolux 5032 B                   | 2        | 4.2%                |
| TES – 137                                 | 2        | 4.2%                |
| Pehamed/PTW – CD lux                      | 2        | 4.2%                |
| Radcal – AGDM +AGLS                       | 1        | 2.1%                |
| **Total**                                 | **48**   | **100%**            |

The physical structure, environmental conditions, instruments, and accessories were assembled from the arrangements recommended by NIST publication 250-37 [11]. The standard photometer and samples were mounted and aligned on a photometric bench with the end of the luminance adapter centralized at the light output from the integrator ball to the photometer detector. The measurements were performed at 25°C ± 2°C ambient temperature, the pre-heating time of the integrating sphere of 30 minutes was used for stabilization of the measurements and the average of 5 measurements.

The Labsphere XTH-2000C system was used for light generation. This system is configured to produce white light with uniform distribution and with spectral distribution referring to CIE illuminator D55 (5500 K). The system consists of integrating sphere of 20 inches with 98% reflective paint, 300W xenon lamp, DAS-050-P-RTA photodetector with UV-VIS-NIR spectrometer model CDS 600 to monitor light beam stability and attenuators variables VA-200-SC to adjust the intensity and model the calibration points.

As a reference standard for luminance, the indication provided by the manufacturer PRC Krochmann model Radiolux 111 with serial number 131015, corrected according to the calibration certificate number DIMIC 1173/2018 INMETRO and corrected by the CIE spectral correction factor, as equation (1):
\[ ccf^*(S_t(\lambda)) = \frac{\int_\lambda S_\lambda(\lambda)S_{rel}(\lambda)d\lambda \int_\lambda S_t(\lambda)V(\lambda)d\lambda}{\int_\lambda S_\lambda(\lambda)V(\lambda)d\lambda \int_\lambda S_t(\lambda)S_{rel}(\lambda)d\lambda} \]  

Where \( S_t(\lambda) \) is the spectral power distribution of the illuminant D55; \( S_\lambda(\lambda) \) is the spectral power distribution of illuminant \( \lambda \); \( S_{rel}(\lambda) \) is the relative spectral response of the reference photometer compared to \( V(\lambda) \), obtained from the manufacturer of the reference photometer, and \( V(\lambda) \) is the spectral light efficiency function for photopic view.

The calibration factor is the ratio of the measurement of the corrected standard by reading the test instrument. Table 2 presents the estimation of the uncertainty of the luminance calibration factor (NE'). For the comparison of the means of the calibration factors with the reference value (1,000) the Student t test was used for a sample. Prior to the application of the t test the Kolmogorov-Smirnov and Shapiro-Wilk tests were applied to verify normal distribution of the sample.

For the analysis of statistical significance, 5% was used as the definition value. When p-value was \( p > 0.05 \), the test result was considered statistically non-significant, maintaining the null hypothesis (Ho), when \( p \leq 0.05 \) was considered statistically significant and rejected Ho. Samples with numbers less than 4 were not evaluated by the t-test because they have low statistical inference power.

| Uncertainty component                        | Relative expanded uncertainty (k = 2) [%] |
|---------------------------------------------|----------------------------------------|
| Calibration of the standard                | 4,3                                    |
| Repeatability of the standard               | 0,01                                   |
| Resolution of the standard                 | 0,05                                   |
| Linearity                                  | 1,0                                    |
| Change of scale                            | 0,5                                    |
| Repeatability of the user instrument*      | 0,02                                   |
| Resolution of the user instrument*         | 0,5                                    |
| Spectral incompatibility correction factor | 0,04                                   |
| Expanded uncertainty                       | 4,5% (k = 2)                           |

*Repeatability: Experimental standard deviation of mean
*The value depends on the calibrated instrument

3. Results and discussions:

The graph of figure 1 shows the response of the luminance meters as a function of the calibration factor (in the columns) for each equipment model and their respective sample sizes (area). The error bar of each equipment model is the standard error that indicates the variation of the sample means or precision. The middle dash indicates the normalized calibration factor for the reference and the up and bottom dash indicates the uncertainty range.

An initial analysis of the calibration factors shown in the graph shows that for 48 equipments studied, the mean values of the calibration factors of 6 of the 10 models evaluated (which represents 62.4% of the total number of the sample) are convergent to the corrected reference value and/or within the range of ± 4.5% uncertainty. This is a significant result since the typical error value of the manufacturing specification of these meters ranges from 5 to 20% [12]. However, 5 of the 10 groups of meters have \( n \leq 2 \) and their interpreted results should be limited to case studies.

Samples with more significant numbers allow the hypothesis test to be performed through statistical inferences about a population, such as the Student t test for a sample that allows the average of a sample to be evaluated against a reference value.
Table 2 shows that the differences regarding the reference for the gauges: Piranha 657, RaySafe - Xi and X2 and Unfors - Light-O-Meter P10 were not statistically significant, that is, the sample mean is not different from the reference value. This result suggests that these equipment’s present considerable accuracy and low spectral sensitivity for measurements performed in white light sources.

| Equipment                                      | Degrees of freedom | Calibration factor average NE’ | Standard error (Accuracy) [%] | Difference from reference [%] | p-value * |
|------------------------------------------------|--------------------|--------------------------------|-------------------------------|------------------------------|-----------|
| RTI - Piranha 657                             | 11                 | 1,030                          | 1,8%                          | 3,0%                         | 0,116     |
| Fluke/Nuclear Associates - 07-621              | 10                 | 1,346                          | 3,6%                          | 34,6%                        | 0,000     |
| RaySafe xi                                     | 7                  | 0,963                          | 1,0%                          | -3,7%                        | 0,006     |
| RaySafe X2                                     | 3                  | 0,983                          | 2,0%                          | -1,7%                        | 0,457     |
| Unfors - Light-O-Meter P10                     | 3                  | 1,041                          | 4,4%                          | 4,1%                         | 0,182     |

*H₀ = p > 0,05 = The sample mean is not different from the reference value;  
Hₐ = p ≤ 0,05 = The sample mean is different from the reference value
It is also shown in Table 2 that Fluke/Nuclear Associates - 07-621 showed a difference of 34.6\% over the reference value with statistical significance, suggesting that there is a relevant error of accuracy and/or significant spectral sensitivity for this equipment, which ultimately implies the need for end-user attention for the use of correction factors through the errors indicated in the calibration certificate.

It is worth emphasizing that not rejecting the null hypothesis of the test means simply that it has not been possible to prove its falsity through the available data, which differs completely from proving its truthfulness and an inference about the accuracy and precision of the general population of the luminance meters may be limited in the present work, since this is a pilot study. A more comprehensive assessment could be better determined by increasing the sample number.

It is important to discuss that standard DIN 5032-7 [12] classifies luminance measurement devices according to their total error limit and defines their components of individual uncertainties. The devices are classified as: class L - highest accuracy have spectral sensitivity (\(f_1\)) \(\leq 2\%\) and total error limit (\(f_{ges}\)) \(\leq 5\%\); A - greater accuracy \(f_1 \leq 3\%\) and \(f_{ges} \leq 7.5\%\); B - mean accuracy \(f_1 \leq 6\%\) and \(f_{ges} \leq 10\%\) and C - lower accuracy \(f_1 \leq 9\%\) and \(f_{ges} \leq 20\%.\) This classification establishes the criteria for classification of the accuracy of its instruments and allows users to know the typical error ranges and their associated uncertainty components of their instruments so that they can conform to their practices, such as the IEC standard 62563-1 which deals with medical image display system evaluation methods requires to stop the execution of its tests a luminance meter having \(f_1 \leq 6\%\) and \(f_{ges} \leq 10\%\).

It is also appropriate to elucidate that the ambient temperature affects the response of these devices and the level of interference depends on each model, according to their respective instruction manuals. Thus, the user must pay attention to the temperature in measurements that demand greater accuracy and/or that are being made in bands, far from the reference temperature (25°C). For example, measurements that are performed in the field for the calibration of the gray scales of radiological monitors may require some correction for the temperature effect, if the environment has a significant difference of the temperature of the calibration or the meter has high dependence for that effect.

Finally, the visualization of medical images is the last stage of a diagnostic chain and the metrology of luminance magnitude has a critical role in this chain. For radiation protection purposes, it is necessary to consider that an error at this stage may compromise any justification for radiation exposure to the patient. Luminosity meters that have significant errors and are used improperly to calibrate and adjust the luminance provided by the devices for displaying medical images may compromise the ash scale displayed in the images and the radiologist’s perception of sharpness, either by the absence or excess brightness. Even if it does not represent a direct risk of radiation to the patient, variations in brightness can produce great damages, since it makes it impossible to identify an existing health problem. 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.

4. Conclusions
This study showed that for 48 equipments studied, the mean values of the calibration factors of 6 of the 10 models evaluated (which represents 62.4\% of the total number of the sample) are convergent to the corrected reference value and/or within the range of ± 4.5\% of uncertainty.

Fluke / Nuclear Associates - 07-621 showed a difference of 34.6\% over the reference value with statistical significance, suggesting that there is a relevant error of accuracy and/or significant spectral sensitivity for this equipment.

Standard 5032-7 [12] classifies luminance measuring devices according to their total error limit and defines their components of individual uncertainties. This classification is important because it allows users to know the typical error bands and their uncertainty components associated with their instruments so that they can adapt to their practices.

The conclusions presented here should be understood as the result of a pilot study and should be validated in later studies so that it can be generalized.
Acknowledgment
The authors acknowledge the Ministério da Ciência, Tecnologia e Inovação (MCTI) for the partial financial and structural support of this work.

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