



## ORIGINAL RESEARCH

# Determination of Calibration Factors and Uncertainties Associated with the Irradiation of MTS-N (LiF: Mg, Ti) Chips with Cesium-137 and X-ray Sources Under Low Doses for Personal Dosimetry in Diagnostic Radiology

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## Abstract

**Purpose:** The purpose of this study was to compare calibration factors for deep dose equivalent Hp (10) and shallow dose equivalent Hp (0.07) between Cesium (Cs)-137 and X-ray sources when they are exposed to same dose and to determine uncertainties with MTS-N (LiF: Mg, Ti) chips when they are exposed to low dose  $\leq 2$ mGy.

**Material and Methods:** Thermoluminescent (TL) chips were annealed at 400°C for one hour and allowed to cool and were subjected to a temperature of 100°C for another two hours using a TLD Furnace Type LAB-01/400. They were then taken to a Secondary Standard Dosimetry Laboratory (SSDL) for irradiation using a Cs-137 source at known doses (0.2-2mGy). A RadPro Cube 400 manual TLD Reader was used to determine corresponding TL signal. The above process was replicated but with a calibrated X-ray unit as the source for calibration.

**Results:** The calibration factors (CF) from the line graph of dose (mGy) against TL signal (count) for Cs-137 source with Hp (10) and Hp (0.07) were  $3.72 \times 10^{-6}$  and  $5.97 \times 10^{-6}$  mGy/count respectively. Those with X-ray source for Hp (10) and Hp (0.07) were  $3.44 \times 10^{-6}$  and  $4.05 \times 10^{-6}$  mGy/count respectively with an overall coefficient of determination ( $R^2$ ) = 0.99. The adjusted maximum percentage deviation between the actual and calculated dose for both sources was -2.74%. The percent (%) deviation of the mean with both sources for Hp (10) and Hp (0.07) was 3.9% and 19% respectively.

**Conclusion:** Adjusted percent deviation from both sources were within the recommended dose limit of  $\pm 30\%$  by the Radiological Protection Institute of Ireland (RPII) and within the International Commission on Radiological Protection (ICRP) limit respectively. Better accuracy was seen for Hp (10) with both sources compared to Hp (0.07). Calibration of the MTS-N chips using both sources was successful and can be used for personal dosimetry.

## Introduction

In the past half century, many books have been written on the characteristics, performance, and theory of thermoluminescence (TL) (1,2). The physical principle of operations of thermoluminescence can be described as a two-way process. The first stage is the change of the system from equilibrium to metastable state by absorption of energy from ultraviolet (UV) or ionizing radiation. The second stage is the relaxation of the system back to equilibrium by energy release such as light with the help of a thermal stimulation (TLD reader). Thus, TL is the thermally stimulated emission of light following the previous absorption of energy from radiation (3, 4). The most commonly used thermoluminescence dosimeters (TLDs) for medical applications are LiF: Mg, Ti, LiF: Mg, Cu, P and Li<sub>2</sub>B<sub>4</sub>O<sub>7</sub>: Mn because of their tissue equivalence. Other TLDs, used because of their high sensitivity, are CaSO<sub>4</sub>: Dy, Al<sub>2</sub>O<sub>3</sub>: C, and CaF<sub>2</sub>: Mn (5-9). Most TLDs are available in various forms (e.g. powder, chips, rods, and ribbons). MTS-N (LiF: Mg, Ti) was used in our study.

Before they are used for clinical or research purposes, the nature of their performance characteristics needs to be verified to rule out possible errors. General use of TLDs require that they are first annealed to erase the residual thermoluminescent (TL) signal using an annealing oven at known temperatures, after which they are placed in a TLD reader. The measurement chamber contains a PMT Tube module, Heating Unit, Exchangeable Filter unit, and nitrogen gas supply unit. Once elements are heated through the heating unit, trapped energy is released in the form of light, from which a Photo Multiplier Tube (PMT) amplifies the light. They are then converted into an electrical signal which is linearly proportional to the detected photon fluence and an electrometer for recording the PMT signal as a charge or current (10, 11). It is important that assessments like homogeneity, sensitivity, reproducibility, linearity, and fading time are carried out to separate chips with poor responses from those with better accuracy. The latter may be associated with error from production line, build-up of impurity over time, and long usage.

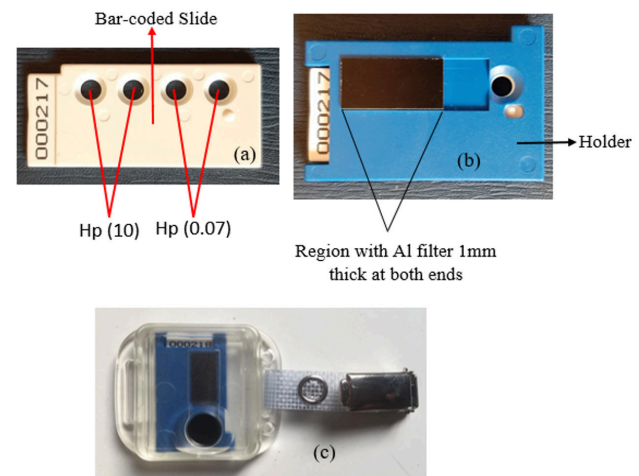
In practice, the calibration factor (CF) is used alongside the TL count to estimate equivalent dose (mSv) (12). It is recommended that the coefficient of determination (R<sup>2</sup>) from the graph of dose (mGy) versus TL signal (count), or vice versa, be close to unity. Several studies have investigated the use of TLD-100 at low doses, which has been considered to have large uncertainty (13). The intention of our study is to expose MTS-N (LiF: Mg, Ti) chips to a dose of 0.2-2mGy in 0.2 mGy steps using a Cs-137 source and an X-ray source to determine CF for Hp (10) and Hp (0.07) respectively. Similarly, our study will determine mean percent deviations associated with both sources.

## Materials and Methods

Prior to this study, assessment of the homogeneity, sensitivity and reproducibility of the TL element were found to be within an accepted limit. The first phase involved

a total of 20 MTS-N (LiF: Mg, Ti) chips each for deep dose [Hp (10)] and shallow dose [Hp (0.07)], which were selected randomly from chips with similar properties. They were arranged on an annealing tray and were positioned in a TLD Furnace Type LAB-01/400 at a temperature of 400°C for one hour and then allowed to cool to room temperature. In order to remove lower peaks they were heated to temperature of 100°C for another two hours. The TL chips were carefully placed in the barcoded slide with four round holes. The first two holes were for Hp (10) and the last two were for Hp (0.07). A 1mm Aluminum (Al) filter was on a portion of the holder, which was meant to compensate for the deep dose [(Hp10)] region. The barcoded slide and holder were concealed within a transparent cover in order to avoid contact with the TL chips (Figure 1a-c).

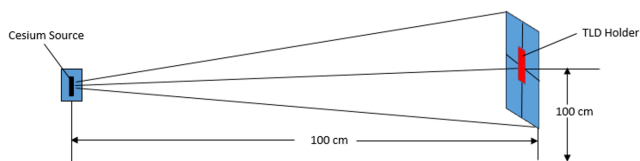
**Figure 1a. Bar-coded slides with the first two housing deep dose Hp (10) and shallow dose Hp (0.07). 1b. Bar-coded slide in a Holder with Al-filters 1 mm thick at both ends. 1c. A TLD badge.**



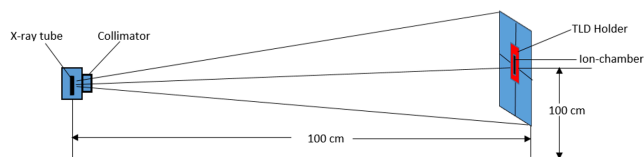
Irradiation was done using a Cs-137 source at Source-to-Object Distance (SID) of 100cm in a Secondary Standard Dosimetry Laboratory (SSDL) to known doses (Figure 2). Each barcoded slide (comprised of four round holes) was exposed to 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0mGy respectively. A RadPro Cube 400 manual TLD Reader (Freiberg Instruments GmbH, Germany) was used to determine corresponding TL count for the irradiated chips as described.

Chips with close sensitivity and good energy response were selected for computing the CFs. The second phase involved the use of a calibrated kilovoltage X-ray unit, an XR Multi detector (radiography), and an ionization chamber. Multiple exposures, up to ten in some cases, were accumulated to achieve 0.2 to 2 mGy in 0.2 mGy increments. The aforementioned doses were achieved using an XR Multi detector with energy range of 40-150kV with a calibrated DCT 100mm ionization chamber (IBA Dosimetry, Germany) for dose verification. The Practical Peak Voltage

**Figure 2. Cesium source setup for calibration of MTS-N (LiF: Mg, Ti)**



**Figure 3a. X-ray setup for calibration of MTS-N (LiF: Mg, Ti) with 10×10cm<sup>2</sup> field size**



**Fig. 3b. MagicMax Basic Unit and DCT 100mm Ionization-Chamber**



(PPV) from the XR Multi detector for RQR5 was 54.33kV, and the HVL and filtration were 2.3 and 3.3mmAl respectively. (Figure 3a and 3b). In this respect, a total of 20 chips were used for Hp (10) and Hp (0.07) each. The same process of annealing and reading was observed as mentioned above. In the same vein, the CF was determined by plotting a linear regression of dose (mGy) against TL signal (count) from which a line equation of  $y=mx+c$  was obtained where  $y$  is the dose (mGy) and  $m$  is the slope of the line graph and is practically regarded as the calibration factor (CF). In order to get the best fit, further adjustments were made for Hp (10) and Hp (0.07) graphs for Cs-137 and X-ray sources respectively. This was necessary for  $R^2$  to be closer to unity. Similarly, an evaluation was carried out to determine the percent deviation of the measured doses in relation to the standard dose. The equation for the percent deviation was

$$\% \text{ Deviation} = \frac{D_{fit} - D_{actual}}{D_{actual}}$$

Where:  $D_{fit}$  represents the dose obtained from the linear fit and  $D_{actual}$  represents the measured dose.

## Results

A line graph of dose (mGy) against TL Signal (count) was plotted for deep dose [Hp (10)] for the Cs-137 source. The obtained line graph was:  $y=3.717 \times 10^{-6}x-1.7054$  (Figure 4a). Here, the slope is practically regarded as the calibration factor for the TLD chips. The coefficient of determination ( $R^2$ ) was 0.9998, which was close to unity. Additionally, there was a strong positive correlation between the standard dose and measured dose ( $r = 1$ ;  $P < 0.001$ ). Similarly, a line graph of dose (mGy) against TL Signal (count) was plotted for shallow dose [Hp (0.07)] for Cs-137. The obtained line graph was:  $y=5.969 \times 10^{-6}x-3.492$  (Figure 4b). The slope is practically regarded as the calibration factor for the TLD chips. The coefficient of determination ( $R^2$ ) was 0.9981. Additionally, there was a strong positive correlation between the standard dose and measured dose ( $r = 1$ ;  $P < 0.001$ ). The maximum and minimum percent deviation in dose response for Hp (10) with Cs-137 source was -25.65 and 0.00 respectively, and a further re-adjustment reduced the maximum percent deviation to -2.23% (Figure 5). Also, the maximum and minimum percent deviation in dose response for Hp (0.07) with Cs-137 source was -15 and 0.98 respectively, and further re-adjustment reduced the maximum percent deviation to 2.74 (Figure 6).

Additionally, the line graph of dose (mGy) against TL Signal (count) was plotted for deep dose [Hp (10)] for X-ray source. The obtained line graph was:  $y=3.443 \times 10^{-6}x+0.0123$  (Figure 7a). The slope is practically regarded as the calibration factor for the TLD chips. The coefficient of determination ( $R^2$ ) was 0.9998. Additionally, there was a strong positive correlation between the standard dose and measured dose ( $r = 1$ ;  $P < 0.001$ ). Considering the line graph of dose against TL Signal (count) for shallow dose [Hp (0.07)] for X-ray source, the line graph obtained was:  $y=4.048 \times 10^{-6}x-0.1874$  (Figure 7b). The slope is practically regarded as the calibration factor for the TLD chips. The coefficient of determination ( $R^2$ ) was 0.9995. There was also strong positive correlation between the standard dose and measured dose ( $r = 1$ ;  $P < 0.001$ ).

The maximum and minimum percent deviation in dose response for Hp (10) with X-ray source was 25.97 and 0.18 respectively, and further re-adjustment reduced the maximum percent deviation to -0.47 (Figure 8). The maximum and minimum percent deviation in dose response for Hp (0.07) with X-ray source was -28.1 and -0.5 respectively, and further re-adjustment reduced the maximum percent deviation to -2.17 (Figure 9).

The mean percent deviation for Hp (10) for Cs-137 and X-ray source was 3.9%, while that of Hp (0.07) for both sources was 19% respectively. Both results were below 20%.

## Discussion

The uncertainty with CFs at a depth of 10mm with Cs-137 and X-ray source was 3.9%. This result appears to be stable with little or no correction factor needed for the photon energy. On the other hand, the CF result for Hp (0.07) with Cs-137 and X-ray source was 19%, which implies that it was ~five times higher than Hp (10). The latter was above

Figure 4a. TL signal response (count) for deep dose, Hp (10).

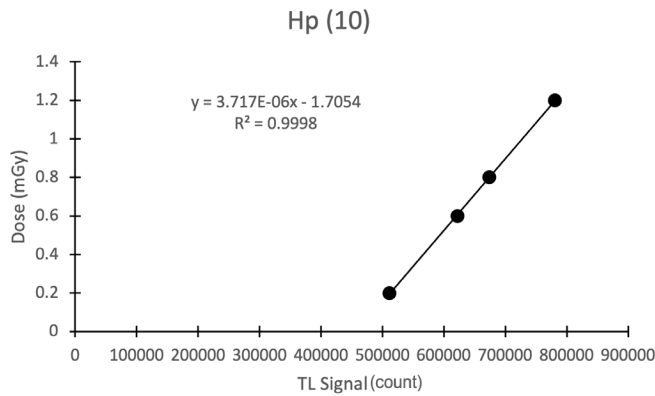


Figure 4b. Shallow dose, Hp (0.07), with Cs-137 source.

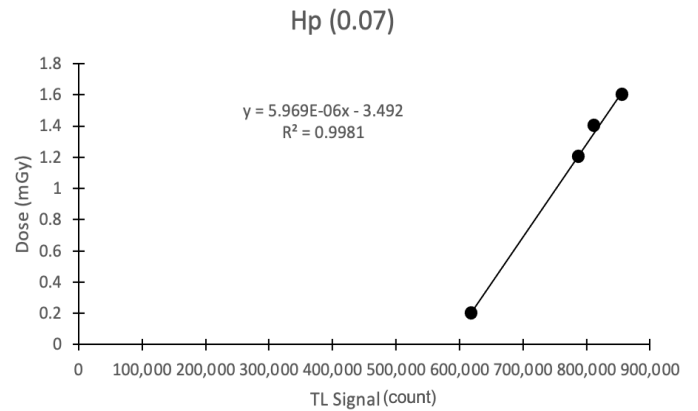


Figure 5. Uncertainty for Hp (10) based on RPII limit of ±30% for Cs-137 source.

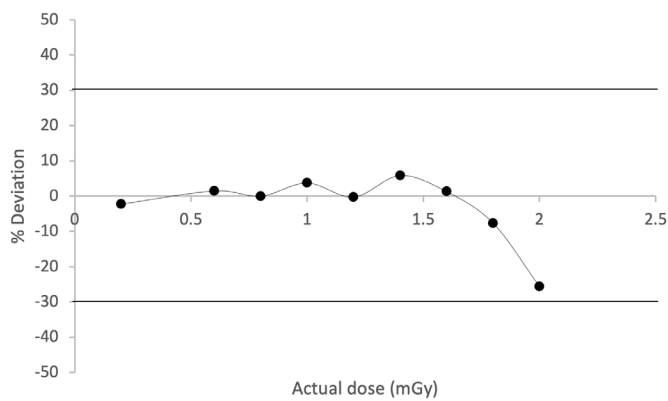


Figure 6. Uncertainty for Hp (0.07) based on RPII limit of ±30% for Cs-137 source.

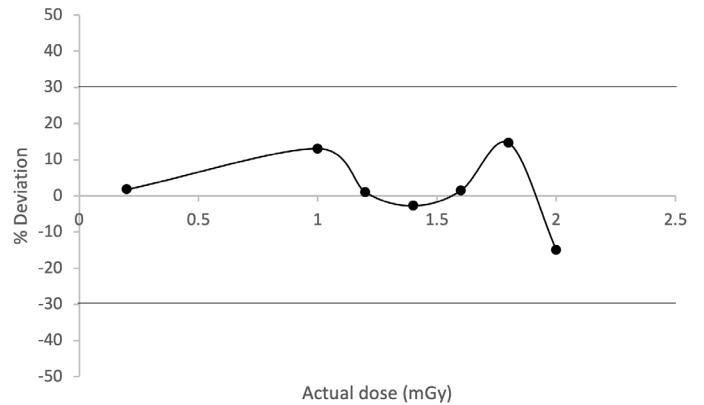


Fig. 7a. TL signal response (count) for deep dose, Hp (10) for Cs-137 source.

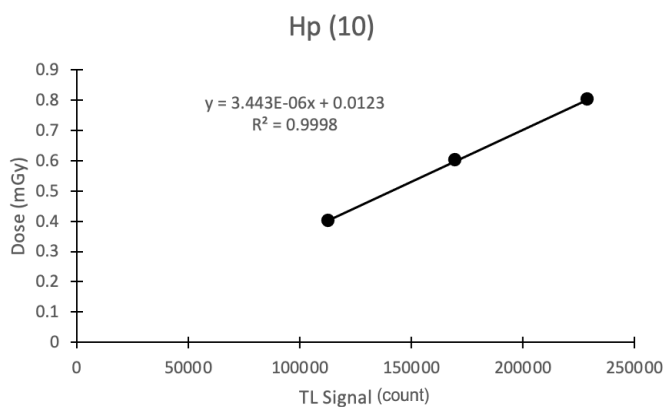
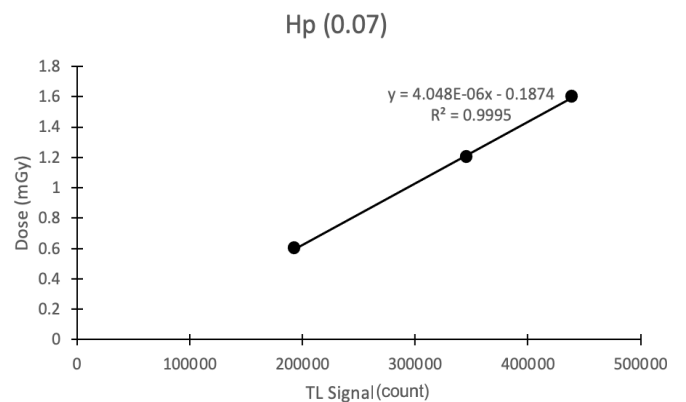
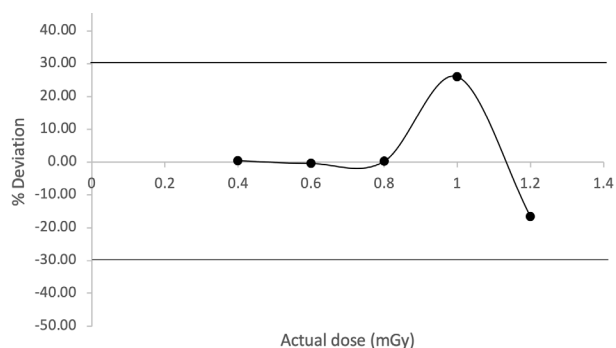


Fig. 7b. shallow dose, Hp (0.07), with X-ray source (56 kV).



**Figure 8. Uncertainty for Hp (10) based on RPII limit of  $\pm 30\%$  for X-ray energy.**

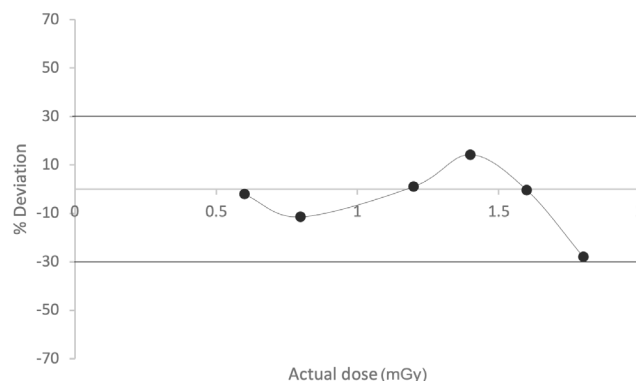


the  $\pm 10\%$  recommended value (14, 15). The reason for this variation could be as a result of the 1mm Al-filter on the barcoded holder for Hp (10), which may have contributed to the accuracy. A pattern of increased responses was noticed for the shallow dose, where Hp (10) and Hp (0.07) for the Cs-137 source were  $3.72 \times 10^{-6}$  and  $5.97 \times 10^{-6}$  mGy/count and for the X-ray source were  $3.44 \times 10^{-6}$  and  $4.05 \times 10^{-6}$  mGy/count respectively. To support this point, a study by Prasetyo et al. investigated two calibration methods that showed that dose at surface ( $84.365 \text{ cGy}/\mu\text{C}$ ) was considerably higher than dose in phantom ( $56.158 \text{ cGy}/\mu\text{C}$ ) at 5cm depth with an exposure dose of 100-4000mGy (16). It was observed that irrespective of the dose applied, CF response of skin or surface dose is higher in terms of numerical values compared to those of the deep dose.

There are few studies on the use of low radiation dose with TL calibration in conventional radiography, where uncertainty in personal equivalent dose is most likely to be high. A study by Herrati et al. pointed out that uncertainty in deviation can reach 60% with low doses (17). Sabar et al., likewise, reported that there could be very high deviation (above 40%) below 0.3mGy (18). This was also supported by Kouakou et al., who evaluated dosimetric performance and uncertainty for TLD-100, and reported that a proportion of TL chips were unable to measure accurately at 0.1-10mGy (19). A study by Kadir et al. investigated the uncertainty associated with the energy response of TLD-100 to an ideal dose, which had a maximum deviation of 125.04% for Hp (0.07) against 45.22% for Hp (10) at 24keV, with the shallow dose exhibiting the higher uncertainty (20).

Our study used doses between the range of 0.2-2mGy with a step of 0.2mGy and observed similar uncertainty. After re-selection, however, the maximum deviation observed fell down to -28.1%, which was within RPII recommendation, which stipulates that "the combined standard uncertainty for measurements of personal dose equivalents at the location of the dosimeter for photons and electrons shall not exceed  $\pm 30\%$  for doses greater than 1 mSv for Hp (10) and 50 mSv for Hp (0.07)" and the ICRP recommendation has a near dose limit of -33% to +50% (13). In the light of this, ICRP also states that 90% of the dose response should be within the trumpet curve. The above recommendations were met

**Figure 9. Uncertainty for Hp (0.07) based on RPII limit of  $\pm 30\%$  for X-ray energy.**



by this study (21). In order to get better accuracy for practical use, further adjustments were made and the maximum percent deviation for Hp (10) with both sources was -2.23 and -0.47, while Hp (0.07) for both sources were -2.74 and -2.17 respectively. Our study was lower compared to a study by Luay et al., who used Cobalt-60 source to evaluate deep dose [Hp (10)], with maximum deviation of 16.08% (22).

The coefficient of determination ( $R^2$ ) for this study was comparable to several studies that investigated the use of TLD-100/100H/600/700 with different energy sources. To support these, a study by Liuzzi et al. investigated the response of TLD-100 to photon (6MV) and electron (5meV, 7meV and 9meV) beams when they are irradiated with 0-10Gy with step of 2Gy (23). The adjustable  $R^2$  from their graph (TL Signal against Dose) was 0.9995, 0.9744, 0.9937 and 0.9962 respectively. The  $R^2$  values obtained were in line with our study for Cs-137 (662keV) and X-ray energy for Hp (10) and Hp (0.07), which were 0.9998, 0.9981, 0.9998 and 0.9995 respectively. This was achieved through the removal of inconsistent TL signals from the raw results. The coefficient of determination ( $R^2$ ) from Yusof et al., who used low energy X-ray (maximum-140kVp) with TLD-100, OSLD and Ionization Chamber (0.9936, 0.9999 and 0.9950), was in line with this study (24). Similarly, the precision of low-dose response using LiF: Mg, Ti exposed to 80kVp (by varying mAs) by Sabar et al. show that below 5mGy the graph was still linear with  $R^2 = 0.9957$ . The response from 0.03-32mGy was also linear ( $R^2 = 0.9991$ ) (18). The  $R^2$  for this study with Cs-137 and kilovoltage X-ray for Hp (10) was 0.9998 and 0.9981 and that for Hp (0.07) was 0.9998 and 0.9950 respectively.

## Conclusion

Our study compared the use of two different sources for MTS-N (LiF: Mg, Ti) calibration. The uncertainty obtained with Hp (10) with both sources was 3.9%, which was within recommended limits. Uncertainty with Hp (0.07) was five times higher than Hp (10), with maximum deviation below 20%, which is still considered acceptable in diagnostic radiology. A continuous re-evaluation program must be carried out to ascertain the reliability of TL chips for personal dosimetry.

## Acknowledgments

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## Conflicts of interest

The authors report no conflicts of interest.

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