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Performance Evaluation of Thermolumniscence Dosimeters in Personnel in-Vivo Dosimetry

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Abstract
Thermolumniscence dosimeters (TLDs) are the most widely used dosimeters for personal dosimetry in radiodiagnosis and radiotherapy for in vivo measurements in most hospitals due to their availability, low cost, tissue equivalent and their ability to withstand high environmental conditions. To evaluate the dosimetric performance effectiveness of TLDs 100H, Calibrated and annealed LiF (Ti), Mg, Cu based TLD badges were officially obtained from Center for Energy Research and Training (CERT), Zaria and were serially irradiated using XR 6000 GE haulum x-ray machine with frequency of 50/60Hz under clinical settings. The TLDs readings were obtained for absorbed doses (personal dose equivalents); Hp(10) and Hp(0.07) through heating using Harshaw 4500 automatic TLD reader at CERT Zaria. The readings obtained ranged between 27.53 mSv and 24.67 mSv in homogeneity test with a factor of 0.12, representing 12% of percentage variation of readings. The mean of the evaluated doses and the standard deviation were 26.26 mSv and 0.02 mSv. The TLD badges homogeneity were 12%, 3.9% collectively and 2.1% separately for reproducibility performance test, 6% averaged for linearity, less than 2% in fading test and 0.11 mSv for self-irradiation performance test. TLDs performance tests conducted were found to satisfy the criteria of the international standard for TL dosimetry system for personal monitoring (IEC 1066 standard) except in the self-irradiation test which reveals slight increase in mSv values (of 0.01 mSv).

Keywords: Thermolumniscence, Dosimetry, Dosimeter, Absorbed dose, Equivalent dose

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INTRODUCTION

X-ray is the most frequently used ionizing radiation source in medicine and it has maintained a key role as a tool in the diagnosis of diseases and therapy and is the major contributor to the effective dose of both the patient and the personnel (Abdullahi *et al*., 2015; Boziari *et al*., 2011; Dlama*et al*., 2014). Despite the various applications of x-rays in medicine, forensic and industries, they pose health effects on human tissues. There is the need therefore, to measure radiation level on occupationally exposed workers using dosimeters to assess the level of exposure with the aim of ensuring safe exposure levels. The effects of radiation are cumulative and lead to increased incidence of cancers, cell deaths, genetic damage and numerous forms of body tissue pathology (Peter*et al*., 2016; Koguchi, Yamamoto &Maria, 2010). The measurement and assessment of absorbed doses by humans using dosimeters is called dosimetry. Radiation dosimeters exhibit several desirable characteristics, but not all dosimeters can satisfy all characteristics. Dosimeter choice must therefore, be made judiciously, taking into account the requirements of the dosimetric situation as it is essential to maintain the quality of high-end equipment procured to provide high quality health care delivery (Kpaku *et al*., 2015; Furetta & Weng, 1997). In medical dosimetry, the required absorbed treatment dose and any other absorbed collateral dose is monitored, and in environmental dosimetry, like monitoring of radon in buildings are other applications of dosimetry (Izewska & Rajan, 2012). Radiation dosimeters are instruments or devices used for measuring or evaluating, directly or indirectly, the radiation exposure, absorbed/equivalent dose, dose rates, kerma and other quantities associated to ionizing radiation(Aya, 2018; Boziari *et al*., 2011). A dosimeter and its reader are called a dosimetry system (Aya, 2018).

Thermolumniscence dosimeter (TLD) incorporates anodized aluminum foil with four thermo-luminescent detectors. These detectors are usually made of lithium fluoride activated with magnesium or calcium fluoride activated, in turn, with manganese (Covens *et al*., 2007; Campos *et al*., 2010). The detectors store the energy received from ionizing radiation. In order to know the amount of radiation received by the dosimeter, it is necessary to heat it to a temperature of 300^{o}C, thus releasing the stored energy in the form of light. The amount of light emitted is proportional to the radiation dose received by each detector (Hill *et al*., 2014). The main advantages are its low cost, easy handling, sensitivity, and that it does not depend only on environmental conditions (Seco *et al*., 2014). Furthermore, it is reusable: Once the dosimeter receives the radiation dose during a period of time, it can be employed again. Other characteristics of TLDs which make it appropriate for dosimetry are as follows; Good tissue equivalence, Low fading, High sensitivity, Good precision and accuracy and good stability under standard environmental conditions (temperature and humidity) (Boziari *et al.,* 2011). Due to the fact that radio-diagnosis and radiotherapy procedures uses diverse types of radiation and several dose levels, different characteristics for the TLDs are required to be used either in diagnosis or therapy (Furetta & Weng, 1997; IAEA,2002). This study examined the homogeneity, reproducibility, linearity, fading and self-irradiation properties of 100H TLDs. The findings of this study has provided performance test indices for comparison with the International Electrotechnical Commission (IEC) 1066 standard which will help healthcare providers (Radiographers, Radiologist, Oncologist and Medical physicist) in the radiation medicine department in the judicious use of TL dosimeters for in vivo dosimetry.

MATERIALS AND METHODS

Materials

A 100H thermoluminescence dosimeters made of LiF:Mn.(Mg)/LiF:Mg which measures and storesthe amount of x-radiation produced by the x-ray machine at a given distance were used. Measured doses are obtained by heating the TLDs to a specific temperature to release the trapped electrons during the ionization event by the radiation which is proportional to the amount of radiation received and this is achieved using a Harshaw 4500 automated TLD reader consisting of data processing electronics notably card drawer assembly, TLD heating system, light measurement system, voltage power supply and data storage system all connected to a video display monitor for graphical data display with a keyboard for instruction that provide communication interface between the reader and other electronic systems. The whole system incorporates two Photomultiplier Tubes (PMTs) in a sliding housing, with both planchet and hot gas (nitrogen or air) heating methods. Hot gas is used for this experiment with subsequent cooling using nitrogen generator system. The system consists of two major components: the TLD Reader and the Windows Radiation Evaluation and Management System (WinREMS) software resident on a personal computer (PC), which is connected to the Reader via a serial communications port. XR 6000 GE HUALUM Medical Radiography Systems with Serial number S0S09084 and frequency of 50/60Hz was used to irradiate the TL dosimeters. The components of this machine work in concert to create a beam of x-ray photons of well-defined intensity, penetrability, and spatial distribution.

Method of performance evaluation test of TLDs

A series of control experiments were performed by irradiating the TLDs to a specified range of doses (0.71 mSv to 35.42 mSv). The quantities measured are personal dose equivalents; Hp (10) and Hp (0.07) representing deep and shallow doses respectively.

Homogeneity of TLD performance check

Eight TL dosimeters were irradiated to the same level of radiation exposure factors (120kV:250mAs). The measurements of the readings obtained were used to analyze the test criteria. The variation of readings of TLDs was evaluated using maximum and minimum values H_{max} and H_{min} as follows (Nguyen, *et al.,* 2001; IEC, 1990)

$$\frac{H_{max}-H_{min}}{H_{min}} \leq 30\% \qquad (2.1)$$

Reproducibility of 100H TLDs

Five TL dosimeters were irradiated using 150kV on 250mAs and their readings were obtained. The procedure was repeated three times in order to evaluate the variations of readings for each TL dosimeter. The mean,$\bar{x}$, standard deviation,σ, and coefficient of variations were calculated for each dosimeter as follows (Sabine *et al*., 2010);

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} \qquad (2.2)$$

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (2.3)$$

Where x_i : Reading of H*(d)

$\bar{x}$: Average reading of H*(d)

$$Co-efficient\ of\ variation = \frac{\sigma_{n-1}\times 100}{\bar{x}} \qquad (2.4)$$

Linearity of 100H TLDs
Five (5) TL dosimeters were irradiated to different exposure factors progressively (in order of increasing dose). The readings were compared to that of a reference dosimeter in order to evaluate percentage variation of readings. The deviation of measured dose from the irradiated dose was calculated using equation (2.5).

$$\frac{Measured\ dose - Irradiated\ dose}{Irradiated\ dose} \times 100 \quad (2.5)$$

Fading (Stability) Test of 100H TLDs

Five TL dosimeters were irradiated at different exposure cycles at an interval of 30 days, two weeks, 48hr, 24hr and 0hr chronologically. All dosimeters were read and normalized to the dosimeters irradiated on day 0.

Self-irradiation check for TLD 100H

Two (2) dosimeters each were stored un-irradiated for 40 days. After the storage period, they were read and evaluated in mSv respectively.

RESULTS AND DISCUSSION
The response uniformity check was performed based on the tests methods of International standard on Thermoluminescent dosimetry system for personal monitoring published by the International Electro technical Commission (IEC) standard; IEC 1066.The results of the tests conducted were presented in tables and evaluated according to the established performance criteria, based on the fulfillment of the levels of accuracy and precision required for this type of service.

Homogeneity test
In the homogeneity test, the maximum and minimum values of personal dose equivalent Hp(0.07) for shallow dose and Hp(10) for deep dose evaluated were 27.53 mSv and 24.67 mSvas shown in Table 3.1.

Table 3.1: Results of the performance test of TLD response to x-radiation in air generated using 120 kv and 250 mAs**.**

S/No.	TLD readings (mSv)	
	Hp(10)	**Hp(0.07)**
1	24.78	25.30
2	26.92	27.44
3	26.16	26.64
4	24.67	25.19
5	27.53	28.01
6	26.05	26.53
7	26.88	27.40
8	27.05	27.53

The mean of the evaluated doses and the standard deviation were 26.26 mSv and 0.02 mSv. A factor of 0.12 was obtained representing 12% of percentage variation of readings using equation 2.1. In general, the results are far below the recommended value by IEC 1066 standard (0.3), this implies that TLD has a very good homogeneity. This finding is in line with the findings of Nguyen *et el.* (2001) and Daniel *et al.* (2000) where both studies obtained 10% and 20% respectively which is within the reference value of < 30%.

Reproducibility Assessment of 100H TLDs

In the reproducibility test shown in Table 3.2, individual TLD sensitivity responses were obtained in the range 32.50 mSv to 35.42 mSv.

Table 3.2: Results of sensitivity response variation of TLD to three given irradiations and readings for Hp (10)

S/No.	Readings obtained according to irradiation (mSv)		
	1st Irradiation	2nd Irradiation	3rd Irradiation
1	33.71	34.95	35.43
2	33.61	33.82	35.42
3	33.21	33.72	33.71
4	34.78	33.33	33.82
5	32.50	35.25	35.04

The standard deviation was found to be approximately 1%. The mean value of the overall irradiations is 34.15 mSv. Generally, in the reproducibility performance test, the determined coefficient of variation has an average value of 2.1% for the dosimeters separately and 3.9% collectively. The average percentage deviations obtained was 4.8%. These values demonstrate that the requirement of the IEC 1066 standard (7.5%) is met. The results are in tandem with Antonio *et al.* (2010) and Daniel *et al.* (2000) whose findings were 7.1% and 3.3% respectively. The findings of this study however, differs with Nguyen *et al.* (2001) who found the collective coefficient of variation for DIS dosimeters as 12% which is above the IEC 1066 standard.

Linearity evaluation of 100 H TLDs

The linearity test for TLDs is shown in Table 3.3, while Figure 3.1 presents the linear correlation graph of the average measured readings of the irradiations against the irradiated dose.

Table 3.3: The results of linearity of responses from TLD for dose range of 0.7 mSv to 8.3 mSv in air.

Irradiated dose (mSv)	Measured dose (mSv) for TLD
0.7	0.71
2.0	2.32
4.2	4.45
6.2	6.30
8.3	8.50

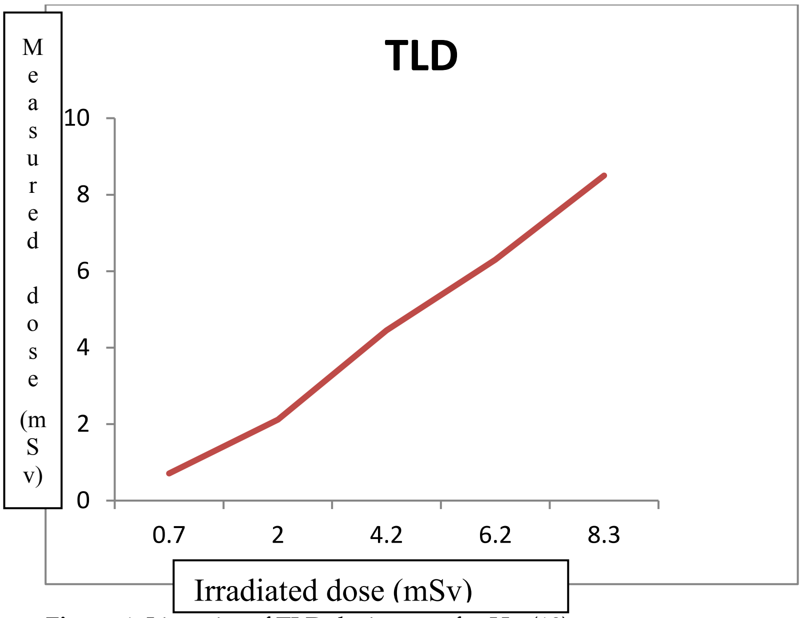

Figure 1: Linearity of TLD dosimeters for Hp (10)

The percentage deviation of measured dose from the irradiated dose was calculated to be between 1.43% and 6.0%. These values lie below 10% indicating that the IEC 1066 standard requirement has been met and are in line with Nguyen *et al.* (2001) and Daniel *et al.* (2000) who found the variation of readings to be 10% each which is also within the standard.

Fading (Stability) Test of 100 H TLDs

The fading of readings was evaluated and presented in table 3.4.

Table 3.4: Data of fading check of TLD response for 30 days storage period at 25 ^{0}C temperature

Storage Period (days)	Average Reading (%)	
	Hp (10)	Hp (0.07)
0	100	100
1	99.1	99.1
2	99.0	98.9
15	99.0	98.9
30	98.3	98.0

The results of the fading (stability) check, has revealed that, there was no significant fading over the storage period. The evaluated loss of signal value was found to be less than 2%. Thus, the IEC 1066 requirement, which is 10% for 90 days under standard test conditions, is met. This result is consistent with Andrew and Braden (2019) whose findings reveals statistical loss of signal in higher temperatures.

Self-irradiation test

The readings obtained for self-irradiation test were found to be 0.11 mSv and 0.09 mSv. This indicates slight elevation of value (0.11 mSv) against the established or recommended 0.10 mSv. This may be attributed to environmental conditions since the research work was carried out in north eastern Nigeria where the weather is relatively high and the transport distance to the reading laboratory is far (covering about 600 Km) which may result in the accumulation of extraneous dose variables.

The summarized TLD performance test results as compared to IEC 1066 (2012) standard is shown in Table 4.5.

Table 3.5: Summary and comparison of results of TLD dosimeter characteristics performance evaluation

Evaluation	IEC 1066 Performance criteria for TLD	Results obtained for Instadose
Badge Homogeneity	The difference between the maximum and minimum evaluated values should not exceed 30%	12%
Reproducibility of Badges	The co-efficient of variation should not exceed 7.5% for each dosimeter separately and all dosimeters collectively	2.1% separately 3.9% collectively
Linearity	The dosimeters response variation should not be more than 10% over the range of 0.1 mSv to 1 Sv	6.0%
Stability	Evaluated values of dosimeters shall not differ from the conventional values by more than 10% for 90 days at 25^0	2.0%
Self-irradiation	The zero point shall not exceed 0.1 mSv after storage period of 30 days.	0.11 mSv

CONCLUSION

The performance of TL dosimetry system has been studied under clinical settings. The dosimeters were evaluated based on the criteria of IEC 1066 standard for personal. The results of the tests carried out were homogeneity, reproducibility, linearity, stability and self-irradiation which have shown that, TLD have a good performance and has pass the entire tests requirement carried out except the slight elevation of mSv value (0.01 mSv) in the self-irradiation test. Based on the result of this study, TL dosimeter system is still good for routine personal x-radiation monitoring in both radio-diagnosis and radiotherapy.

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