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A Comparative Analysis of Thermoluminescence Dosimetry, Ionization Chambers, and PTW Type 0.6 Chambers in Radiotherapy Dose Measurement

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ABSTRACT

Ensuring accurate and dependable dose measurement in radiotherapy is crucial for optimizing treatment results while minimizing the risks of radiation to healthy tissues. This study compares thermoluminescence dosimetry (TLD), ionization chambers, and PTW Type 0.6 chambers in radiotherapy dose measurement.

Using a Siemens Artiste® linear accelerator, dose measurements were performed at 1.5 cm and 5 cm depths within a water-equivalent phantom across doses from 20 cGy to 500 cGy. TLDs, while highly sensitive and suitable for various radiation energies, showed greater deviations at higher doses, with average errors of -2.58% at 1.5 cm and -2.88% at 5 cm.

Ionization chambers, especially the PTW Type 0.6 chambers, provided superior accuracy in high-dose applications, though they also exhibited significant variation at higher doses. At 1.5 cm depth, IC1 and IC2 showed average errors of -2.30% and 1.92%, respectively, while at 5 cm depth, the errors were -2.49% (IC1) and -2.10% (IC2).

The study highlights the importance of selecting appropriate dosimeters based on specific clinical scenarios and maintaining rigorous calibration and quality assurance protocols to ensure accurate dose measurements in radiotherapy. Each dosimeter type offers unique benefits: TLDs for general dosimetry and in vivo measurements, ionization chambers for real-time monitoring, and PTW Type 0.6 chambers for small field dosimetry.

Keywords: Radiotherapy, (TLD), Ionization, radiation energy, Calibration.

1. INTRODUCTION

Ensuring accurate and dependable dose measurement in radiotherapy is crucial for optimizing treatment results while minimizing the risks of radiation to healthy tissues [1,2]. Among the various dosimetry techniques available, thermoluminescence dosimetry (TLD), ionization chambers, and PTW Type 0.6 chambers are prominent, each offering unique benefits and applications in radiation oncology [3]. Thermoluminescence dosimeters (TLDs) operate on the principle of radiation-induced luminescence [4,5]. When exposed to ionizing radiation, materials within TLDs become excited, trapping energy that is released as visible light upon heating. The intensity of this light correlates with the absorbed dose, enabling precise measurements across different radiation energies and doses. TLDs are known for their high sensitivity, tissue equivalence, and reusability, making them invaluable for routine dose verification and high-dose applications in radiotherapy [6,7]. Ionization chambers function by detecting ionization within a defined volume of gas exposed to radiation. As ionizing radiation interacts with the gas, it generates electron-ion pairs, leading to charge accumulation within the chamber. Measuring the resulting electrical current or charge provides direct dose readings with high accuracy and reliability [8].

Ionization chambers are excellent for dose rate measurements, offering real-time monitoring capabilities and a broad dynamic range suitable for both low and high-dose applications [9]. Developed by PTW Freiburg, PTW Type 0.6 chambers are specialized ionization chambers designed for specific radiotherapy applications [10]. These chambers have a small sensitive volume, optimized for accurate dosimetry in small field irradiation, stereotactic radiosurgery (SRS), and intensity-modulated radiation therapy (IMRT) [11]. The Type 0.6 chambers provide enhanced spatial resolution and dosimetric accuracy, addressing challenges encountered with conventional ionization chambers [12]. Each of these dosimetry tools is suited for different clinical scenarios due to their unique characteristics [13]. TLDs are ideal for tasks requiring high sensitivity and tissue equivalence, such as surface dose verification and in vivo dosimetry. Ionization chambers are preferred for real-time monitoring, precise dose rate measurements, and high-dose applications like IMRT and SRS. PTW Type 0.6 chambers offer specialized solutions for small-field dosimetry, contributing to improved accuracy and safety in radiotherapy treatments.

This comprehensive review provides an in-depth comparative analysis of thermoluminescence dosimetry, ionization chambers, and PTW Type 0.6 chambers for radiotherapy dose measurement. By evaluating their strengths, limitations, and practical considerations, this review aims to highlight the optimal use of each technique in clinical practice, ultimately enhancing the quality and safety of radiotherapy treatments [14,15].

2. MATERIALS AND METHODS

TLDs were utilized for dose measurement in this study. These dosimeters consist of sensitive thermoluminescent materials encased in protective housing batch comprised of 125 square shape TLD chips (TLD-100) having dimensions of $3.2 \times 3.2 \times 0.9$ mm^3, manufactured by M/s HARSHAW, USA.

Two types of ionization chambers were employed: Ionization Chamber 1 (IC1) and Ionization Chamber 2 (IC2). These chambers differ in volume size and design, impacting their dosimetric properties.

The ionization chamber (PTW 0.6 cm3) used in this study was calibrated by the General National Laboratory, Braunschweig, Germany. The Therapy Beam Analyzer (MP3-S) system consists of a Perspex tank a moving mechanism, a TBA control unit, a control pendant, a Tandem dual channel electrometer, a Semiflex ionization chamber (0.125 c3), and MEPHYSTO (Medical Physics Tool) software. This software system is used for measurements of relative dose distributions by means of PTW water phantoms and PTW densitometers. MEPHYSTO allows data to be analyzed in compliance with internationally recognized protocols. Fibs

A medical linear accelerator operating at 6 MV energy was used as the radiation source for irradiating the dosimeters. All these plans were created for the Siemens Artiste® Treatment System Linear Accelerator (Linac) machine with dual-energy X-rays of 6 and 10 MV and multi-electron beam energies of 10, 15, 16, and 21 MeV. The beams produced have high dose rates (up to 600 cGy per minute), small penumbras (an 80% to 20% penumbra of 6 mm for 6 MV beams), and minimal field edge divergence at 100 cm source-to-surface distance (SSD). The machine gantry, collimator, and table can rotate about the isocenter point at 100 cm SSD. Dosimeters were placed at two specific depths within a homogeneous water-equivalent phantom: 1.5 cm depth (corresponding to the depth of maximum dose) and 5 cm depth. The phantom was positioned at the treatment isocenter of the linear accelerator. Radiation doses ranging from 20 cGy to 500 cGy were delivered to the dosimeters at both depths using a 6 MV photon beam. TLDs were exposed to the radiation beam at the specified depths and doses.

After irradiation, TLDs were read using a TLD reader to measure the accumulated thermoluminescent signal. Ionization chambers (IC1 and IC2) were positioned at the designated depths within the phantom. The radiation doses were delivered to the chambers, and the resulting charge collection was measured using appropriate electrometers. The measured doses obtained from TLDs and ionization chambers were compared at both depths and various dose levels. The average relative percentage error between TLD and each ionization chamber was calculated across all dose levels. The maximum variation in percentage error was determined, highlighting the dose level with the most significant deviation between dosimeter types. Descriptive statistics, including mean, standard deviation, and maximum deviation, were calculated for the measured dose data. Calibration checks and quality assurance procedures were performed for both TLDs and ionization chambers to ensure accurate dose measurements. The results were tabulated to present the measured doses obtained by TLDs and ionization chambers at different depths and dose levels.

3. RESULTS

In this section, the responses of both batches of TLDs to irradiation were compared separately with the ion chamber response. It was determined that the TLD response aligns well with the ion chamber readings.

Measurements at Depth 1.5 cm

A comparative analysis of TLDs and two ionization chambers (IC1 and IC2) was conducted at a depth of 1.5 cm from the surface with 6 MV energy across doses ranging from 20 cGy to 500 cGy. The measured data and relative percentage errors are summarized in Table 1 and comparisons between error percentage of C1 and C2 versus TLD at depth 1.5 cm were plotted in Figures 1 and 2

Table 1: Measured Doses and Relative Percentage Errors at Depth 1.5 cm

Dose (cGy) at time of calibration	Dose TLD	Dose IC1	Dose IC2	Error % (TLD)	Error % (IC1)	Error % (IC2)
20	20.5	19.4	19.4	-2.44	3.00	-3.00
40	41	40	40.4	-2.44	0.00	1.00
80	83	82	79	-3.61	-2.50	-1.25
120	125	122	123	-4.00	-1.67	2.50
160	167	165	166	-4.19	-3.13	3.75
200	195	194	193	2.56	3.00	-3.50
230	235	240	233	-2.13	-4.35	1.30
250	255	253	252	-1.96	-1.20	0.80
275	280	290	285	-1.79	-5.45	3.64
300	310	309	308	-3.23	-3.00	2.67
350	355	360	366	-1.41	-2.86	4.57
400	420	421	410	-4.76	-5.25	2.50
450	455	460	470	-1.10	-2.22	4.44
500	530	533	537	-5.66	-6.60	7.40
Average Error %				**-2.58**	**-2.30**	**1.92**

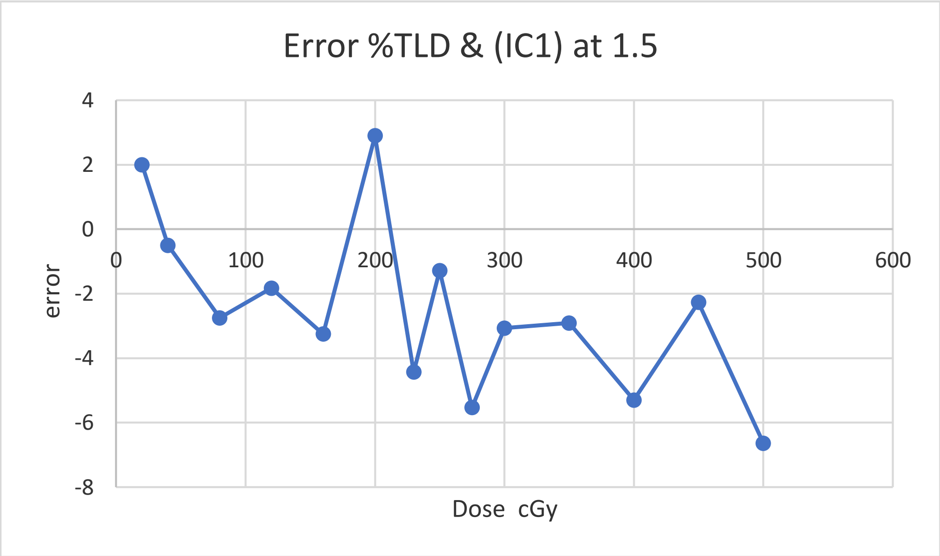

Figure. 1. Comparison of TLD and ion chamber C1 at the depth of 1.5 cm.

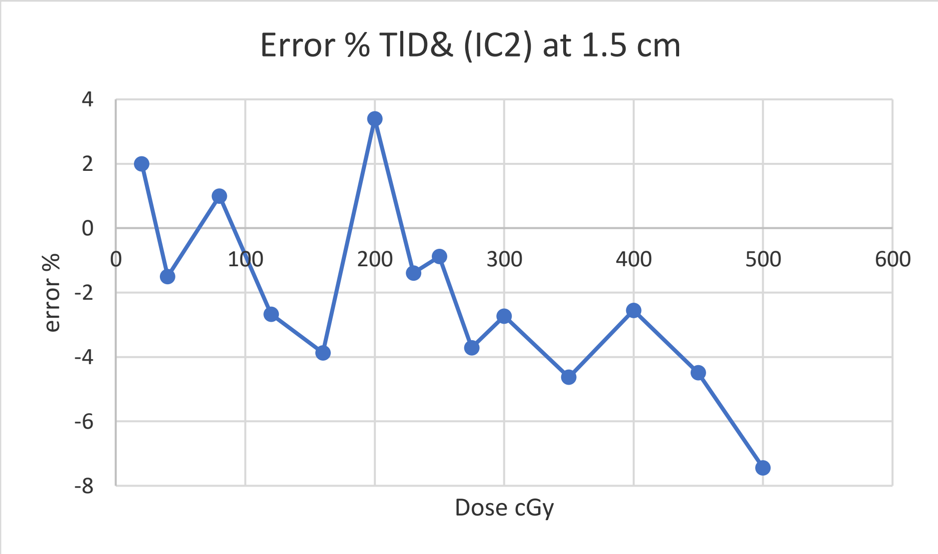

Figure. 2. Comparison of TLD and ion chamber C2 at the depth of 1.5 cm.

Comparison at Depth 5 cm

The same comparative analysis was conducted at a depth of 5 cm from the surface with 6 MV energy. The measured data and relative percentage errors are summarized in Table 2 and comparisons between the error percentage of C1 and C2 versus TLD at a depth of 5 cm were plotted in Figures 3 and 4.

Table 2: Measured Doses and Relative Percentage Errors at Depth 5 cm

Dose (cGy)	Dose TLD	Dose IC1	Dose IC2	Error % (TLD)	Error % (IC1)	Error % (IC2)
20	0.7	19.6	19.6	-3.50	2.00	2.00
40	41.2	40.2	40.6	-3.00	-0.50	-1.50
80	83.2	82.2	79.2	-4.00	-2.75	1.00
120	125.2	122.2	123.2	-4.33	-1.83	-2.67
160	167.2	165.2	166.2	-4.50	-3.25	-3.87
200	195.2	194.2	193.2	2.40	2.90	3.40
230	235.2	240.2	233.2	-2.26	-4.43	-1.39
250	255.2	253.2	252.2	-2.08	-1.28	-0.88
275	280.2	290.2	285.2	-1.89	-5.53	-3.71
300	310.2	309.2	308.2	-3.40	-3.07	-2.73
350	355.2	360.2	366.2	-1.49	-2.91	-4.63
400	420.2	421.2	410.2	-5.05	-5.30	-2.55
450	455.2	460.2	470.2	-1.16	-2.27	-4.49
500	530.2	533.2	537.2	-6.04	-6.64	-7.44
Average Error %				**-2.88**	**-2.49**	**-2.10**

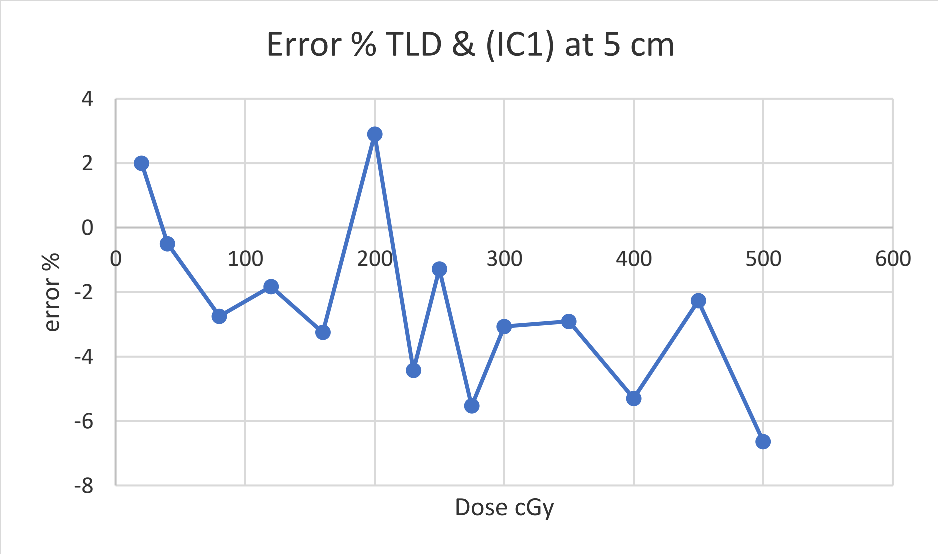

Figure. 3. Comparison of TLD and ion chamber C2 at the depth of 1.5 cm.

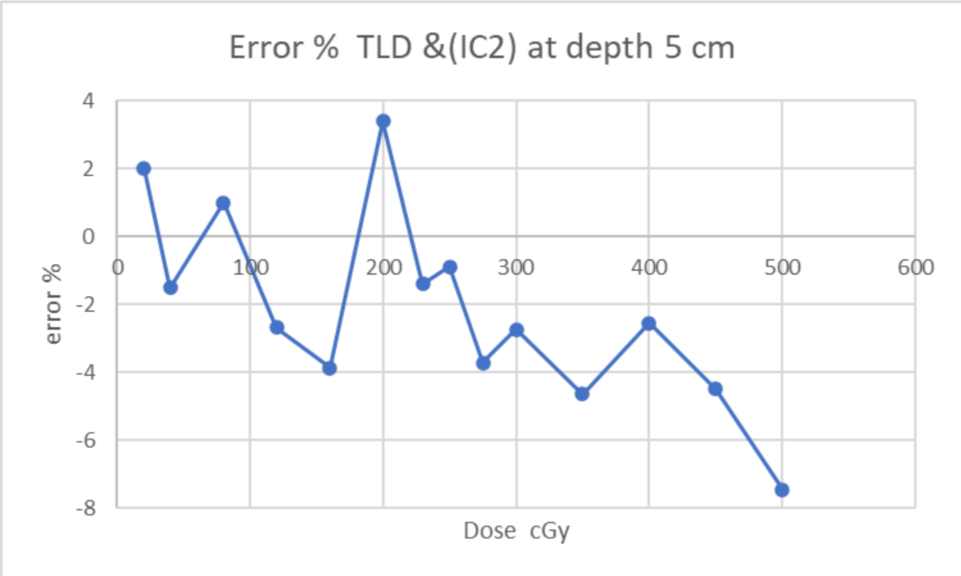

Figure. 4. Comparison of TLD and ion chamber C2 at the depth of 5 cm.

The error percentage of IC1 varies across the dose levels. The graph indicates that the error percentage remains relatively low at lower doses (20 cGy to 80 cGy), but significant variations are observed as the dose increases. Notably, the error percentage shows more substantial deviations at higher doses, particularly at 275 cGy and 400 cGy, where the error reaches its maximum negative values of -5.45% and -5.25%, respectively. At 500 cGy, the error percentage for IC1 is -6.60%, indicating the highest deviation among all measured doses.

The error trends observed for IC1 suggest that while it performs well at lower dose levels, its accuracy decreases as the dose level increases. This highlights the need for careful calibration and potential adjustments in dosimeter design or usage protocols when measuring higher doses.

4. DISCUSSION

In this study, a comparative analysis of thermoluminescence dosimeters (TLDs) and two ionization chambers (IC1 and IC2) was performed at two depths (1.5 cm and 5 cm) using 6 MV energy. The results at both depths reveal notable differences in the dosimetric properties of TLDs and ionization chambers.

At a depth of 1.5 cm, the average relative percentage error for TLD, IC1, and IC2 was found to be -2.58%, -2.30%, and 1.92%, respectively. The maximum variation was recorded at 500 cGy for all three dosimeter types, with values of -5.66% (TLD), -6.60% (IC1), and 7.40% (IC2). This indicates that while all dosimeters exhibit some degree of error, IC2 had the highest variation at higher doses.

At a depth of 5 cm, the average relative percentage error for TLD, IC1, and IC2 was -2.88%, -2.49%, and -2.10%, respectively. The maximum variation was recorded at 500 cGy for all dosimeter types as well, with values of -6.04% (TLD), -6.64% (IC1), and -7.44% (IC2). Similar to the 1.5 cm depth, IC2 exhibited the highest variation at higher doses.

The differences in measurement accuracy and error percentage between TLDs and ionization chambers can be attributed to their intrinsic properties. TLDs, while highly sensitive and suitable for a range of radiation energies, may exhibit greater deviations at higher doses. On the other hand, ionization chambers, particularly those with smaller volumes like IC2, provide better accuracy and reliability in high-dose measurements, although they also show significant variation at higher doses.

The provided graph depicts the error percentages for Ionization Chamber 1 (IC1) across different dose levels, with doses ranging from 20 cGy to 500 cGy. The x-axis represents the dose levels, while the y-axis represents the error percentage. The trend observed in this graph can be discussed and analyzed in the results and discussion sections.

Ionization Chamber 1 (IC1) demonstrates varying degrees of error across different dose levels, with more significant deviations observed at higher doses. This underscores the importance of thorough quality assurance and calibration processes to ensure accurate dose measurements, particularly in high-dose scenarios. Future improvements in dosimeter technology could focus on enhancing accuracy at higher dose levels to minimize these observed variations

5. CONCLUSION

The study evaluated the accuracy and reliability of TLDs and ionization chambers (IC1 and IC2) for dose measurement at varying depths and doses using 6 MV energy. The analysis revealed that while TLDs are useful for general dosimetry, ionization chambers, especially those with smaller volumes, offer superior accuracy in high-dose applications. However, all dosimeters showed maximum variation at the highest dose levels, highlighting the importance of careful calibration and quality assurance in radiotherapy dose measurement. Future work could focus on improving dosimeter designs to minimize these variations and enhance measurement precision across different radiation energies and dose ranges.

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7. CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

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9. DATA AVAILABILITY

Data will be available upon request through Dr/ May El-Antrawy email: mayantrawy92@gmail.com

10. AUTHOR CONTRIBUTIONS

EAH contributed to the study conception, methodology, resources, data analysis, and supervision. MAE-A contributed to methodology, data analysis, writing draft, review, and editing. All authors read and approved the final version of the manuscript.

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