Feasibility Study – Extending the Clinical Utility of Optically Stimulated Luminescent Dosimeters (OSLDs)

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ABSTRACT

While OSLDs are widely used in clinical radiotherapy, their utility is typically limited to an accumulated dose of 10 Gy due to the filling of deep electron traps that causes sensitivity changes. This study evaluates UV-assisted annealing as a high-energy method to clear deep electron traps, aiming to restore consistency and extend the clinical lifespan of OSLDs through an analysis of UV energy and energy dependence. Measurements were performed using a microSTAR®ii reader and a custom bleaching chamber equipped with both conventional fluorescent lamps and UV-C sources (254 nm). The study utilized nine "clinically retired" nanoDot™ OSLDs, all featuring accumulated dose histories exceeding 10 Gy. The evaluation was conducted in two stages. First, annealing reproducibility was tested by subjecting the OSLDs to repeated 24-hour UV cycles; between cycles, calibration curves were generated using a 6 MV beam with field of 10x10cm^2 at doses from 50 to 1000 MU. Second, energy dependence was analyzed by exposing a separate set of OSLDs to 6, 10, and 18 MV photon fields (10x10cm^2) at 50 and 150 MU. This allowed for a comparison of cleaning efficacy and recovery consistency across different radiation energy levels. Analysis demonstrated that calibration curves remained statistically consistent across multiple 24-hour annealing cycles. The reproducibility of the calibration slopes was high, with the standard deviation of the mean ranging from 3.58% to 7.12% across the study set. OSLDs demonstrated energy dependence when their dose histories exceeded 15 Gy. UV annealing was not determined to contribute to high dose history OSLD energy dependence. The consistency in post-anneal calibration curves suggests that UV bleaching effectively extends OSLD utility beyond a 10 Gy lifetime dose. However, prior to clinical adoption, end-to-end testing must be performed to ensure measurement accuracy within a standard clinical workflow.

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INTRODUCTION

TG-191 recommends retiring nanoDot™ OSLDs after an accumulated lifetime dose of 10 Gy due to changes in detector response associated with dose-history effects. As clinics continue to rely on aging OSLD inventories, extending the usable lifespan of these detectors has become an important practical consideration.

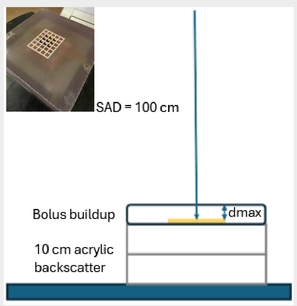
Previous work demonstrated that incorporating 254 nm UV-C light into the bleaching process can reduce the dose-history effects responsible for changes in OSLD sensitivity. UV photons have sufficient energy to interact with deeper trapping centers that contribute to long-term response changes.

The primary objective of this work was to determine whether repeated UV-assisted annealing could maintain consistent calibration characteristics in clinically retired nanoDot™ OSLDs with accumulated dose histories exceeding 10 Gy. If the calibration is determined consistent across multiple UV annealing cycles, OSLDs with high accumulated dose histories can confidently reuse the same initial calibration factor. Additionally, the established megavoltage energy response of OSLDs was evaluated when utilizing UV annealing.

METHODS AND MATERIALS

The UV-annealing system is a wooden box containing two 254 nm mercury-vapor UV-C lamps positioned above an acrylic support sheet and two visible-spectrum bulbs positioned below it. The acrylic sheet held the OSLDs and allowed visible light transmission while blocking UV-C wavelengths, ensuring that the detectors received the intended UV exposure from above. NanoDot™ OSLDs retired from clinical use were selected for testing. Prior to irradiation, all OSLDs underwent a 24-hour UV-assisted bleaching cycle and background measurements were acquired using a microSTAR®ii reader. The data collection process for testing calibration consistency and energy dependence is shown in Figures 1 and 2.





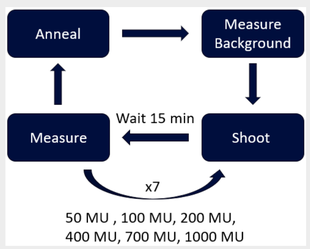


Figure 1. Workflow for Calibration Consistency Data Collection (Each OSLD Received 2,450 MU per Irradiation Cycle)

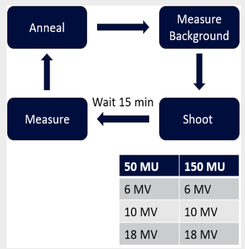


Figure 2. Process for energy dependence data collection.

RESULTS

Figure 3 shows the $\sigma/\bar{x}$ of each OSLD's CF across multiple annealing cycles. The $\sigma/\bar{x}$ significantly increases with increasing accumulated dose. Over the first 3 cycles of annealing, for an accumulated dose of 51 Gy, the $\sigma/\bar{x}$ for the majority of OSLDs is below 5%. The $\sigma/\bar{x}$ barely increases when the fourth cycle is included, corresponding to an experimentally accumulated dose of 75.5 Gy, and the $\sigma/\bar{x}$ exceeds 10% over five cycles, corresponding to an accumulated dose of 100 Gy. There is, then, a breakdown in CF consistency at some dose history between 75 Gy and 100 Gy.

Table 1 shows the variable energy response of OSLDs with high dose accumulation. Most of these OSLDs did not have a recorded dose history, but those that did might permit an extrapolation of response to those without a recorded history. Those with a dose history > 1300 cGy showed a significantly higher energy dependency at 50 MU than the others, reflected by a red or white colored cell. It might be assumed that OSLDs without a recorded history and red or white $\sigma/\bar{x}$ cells had dose histories > 1300 cGy. Interestingly, this energy dependence was not consistent across MUs. Between 50 and 150 MU, $\sigma/\bar{x}$ was only within a 5% difference for two of the seven OSLDs with red or white colored cells. Lower dose history OSLDs maintained energy independence within 5% that has been well established in literature.

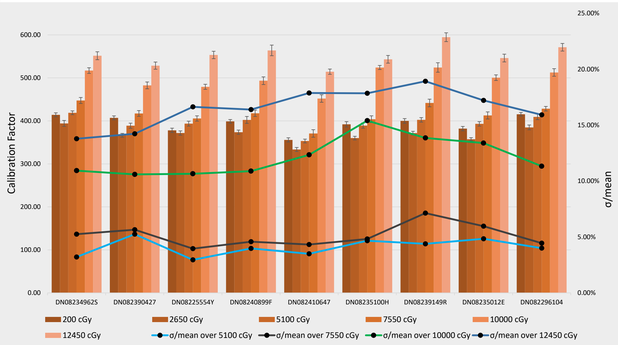


Figure 3. *the evolution of CF values for each OSLD over 98 Gy of delivered dose with associated $\sigma/\bar{x}$ evaluations. The columns correspond to the CF value of a given annealing cycle. The marked line graphs represent the $\sigma/\bar{x}$ evaluated over the labeled number of cycles. The degradation of CFs is visible in the increasing column heights. And the deviation from CF consistency is shown by the increasing $\sigma/\bar{x}$ over increasing annealing cycles corresponding to increasing accumulated dose.*

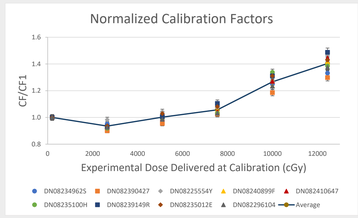


Figure 4. *The normalized CFs for all OSLDs over the course of the experiment. A clear increase is of CFs is shown correlating with increased accumulated dose.*

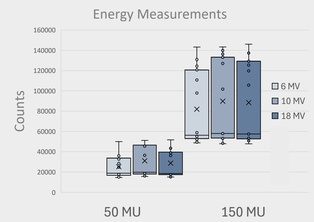


Figure 5. Energy response of annealed OSLDs at 50 MU and 150 MU following high-dose accumulation. The boxplots compare signal counts across three photon energies: 6 MV, 10 MV, and 18 MV.

Table 1. Normalized energy response data. The $\sigma/\bar{x}$ is green for $\sigma/\bar{x} < 5\%$, uncolored for $5\% \leq \sigma/\bar{x} < 10\%$, and red for $\sigma/\bar{x} \geq 10\%$.

OSLD ID	Dose History (cGy)	50 MU Normalized Signal 6 MV	50 MU Normalized Signal 10 MV	50 MU Normalized Signal 18 MV	50 MU σ/mean	150 MU Normalized Signal 6 MV	150 MU Normalized Signal 10 MV	150 MU Normalized Signal 18 MV	150 MU σ/mean
DB08914533N	n/a	-0.87	-0.78	-0.84	2.9%	-0.82	-0.86	-0.88	1.6%
DB09301477M	n/a	-0.74	-0.66	-0.75	2.8%	-0.72	-0.75	-0.76	0.9%
DB088228578	n/a	-0.82	-0.76	-0.84	2.5%	-0.79	-0.84	-0.84	1.7%
DB08412470Y	n/a	-0.87	-0.79	-0.85	2.5%	-0.81	-0.86	-0.87	1.8%
DB08012883N	n/a	0.74	1.50	1.20	9.3%	-0.99	1.28	1.00	37.6%
DB08514540W	n/a	-0.91	-0.81	-0.85	3.3%	-0.88	-0.85	-0.88	1.0%
DB08207298J	n/a	-0.28	1.41	0.87	24.5%	0.62	1.21	1.13	8.0%
DN08159942M	n/a	0.59	1.43	1.22	11.0%	0.29	1.38	1.31	15.4%
DN084778396	n/a	-0.96	-0.86	-0.92	3.4%	-0.90	-0.94	-0.93	1.3%
DN07939216T	n/a	1.68	1.76	1.81	1.4%	1.46	1.47	1.54	0.9%
DN084459551	1727.6	0.01	0.63	0.61	11.0%	0.88	0.39	0.49	7.5%
DN07812752Z	1010.4	-1.06	-0.98	-1.03	2.9%	-0.97	-1.01	-0.93	2.4%
DN08627589F	1047.6	-0.90	-0.84	-0.88	2.0%	-0.87	-0.88	-0.93	1.8%
DN077062172	1473.5	0.34	1.33	0.77	13.5%	0.98	1.20	1.10	2.7%
DN08095956A	1270.3	-1.03	-0.94	-1.02	3.2%	-0.90	-1.00	-1.01	3.9%
DN078133245	1743	0.42	1.47	1.17	13.8%	1.14	1.38	0.86	6.3%
DN08097294M	1730.2	0.70	1.39	0.81	9.5%	1.16	1.04	1.35	3.6%

DISCUSSION

For over half of the tested OSLDs, $\sigma/\bar{x}$ varied by less than 5% over 4 annealing cycles with a total accumulated dose of 7350 cGy.Consistent calibration curves over this accumulated dose exceeded expectations. Increasing variability was shown for CFs applied to batches of OSLDs, which was expected, assuming individual device calibration would be the most accurate to raw measurements. The variability of batch calibration is shown below.

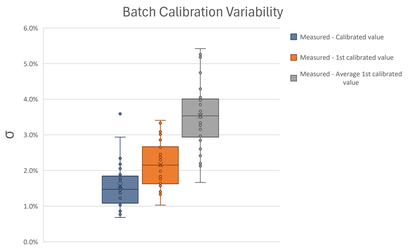


Figure 6. Batch calibration variability (σ) across all monitor units (MU) for each comparison group. The distribution within each box plot correlates with absorbed dose, spanning from lower doses (e.g., 50 cGy) at the bottom to higher doses at the top.

The energy dependence testing had mixed results. Of the 17 tested OSLDs, 7 had a $\sigma/\bar{x} > 5\%$ between energies at 50 MU, and 5 had a $\sigma/\bar{x} > 5\%$ between energies at 150 MU. The extended range of $\sigma/\bar{x}$ between all measurements, $0.89\% \leq \sigma/\bar{x} \leq 37.65\%$, and over 25% of the OSLDs having $\sigma/\bar{x} > 5\%$, does not provide the confidence to assert that these devices are energy dependent. In fact, TG-191 sites an OSLD energy dependence "in excess of 1-2%". Then, a 5% threshold may actually be quite generous, in which case, an additional 6 measurements would have $\sigma/\bar{x} > 3\%$. This serves to add weight to the suggestion to individually calibrate nanoDot™s at each energy available to a linac.

CONCLUSIONS

Calibration factors of nanoDot™ OSLDs remained consistent across multiple annealing cycles and with dose deposition up to around 80 Gy. With increasing dose accumulation, the calibration factors deviated from consistency with initial measurements, showing that UV annealing is incapable of completely cleaning deep traps that contribute to the dose-history-dependence of Al2O3:C type OSLDs. UV annealing was also shown to not affect the energy response of nanoDot™s, but that those OSLDs did show variable responses between devices, especially correlating with higher dose accumulation. Energy dependent calibration and monitoring is required beyond 15 Gy accumulated dose history. The results of these experiments show that the clinical utility of nanoDot™ OSLDs may be extended well beyond the recommended 10 Gy lifetime when UV annealing is performed.

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