Characterization of an optically stimulated dosimeter for dentomaxillofacial dosimetry

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Objective. The objective of this study was to examine the suitability of optically stimulated luminescent dosimeters (OSLD) for point dosimetry of maxillofacial radiographic examinations.

Study design. The dose response of OSLD nanoDot dosimeters was evaluated over the range of 10 μGy to 4900 μGy x-radiation. The angular dependence of the OSLD nanoDots was examined and compared with that of thermoluminescent dosimeter (TLD) chips. The concordance between OSDL- and TLD-measured absorbed doses at selected anatomic sites in an anthropomorphic phantom was examined.

Results. OSLD-measured doses were not significantly different from the actual delivered dose, as determined by an ionization chamber. The dose response is linear over the dose response over the examined dose range. Angular variation of OSLD dosimeters ranged from 88% to 109%; however, the magnitude of this variation was not significantly different from that of TLDs. There was a good concordance between OSLD- and TLD-measured absorbed doses.

Conclusions. The OSLD nanoDots dosimeter system performs as well as currently used TLD systems and effective dose estimates using this new system did not differ significantly from current TLD-based dose estimates. (Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;112:793-797)

The basic premise of diagnostic radiology is that the benefit from the examination outweighs potential risks from radiation exposure. The principal detriment from diagnostic x-radiation is radiation-induced neoplasia: the magnitude of this risk increases with radiation dose. Thus, knowledge of the dose delivered by a diagnostic radiographic examination is key for its risk-benefit analysis. Typically, these doses are determined using dosimeters placed at several sites in a tissue-equivalent anthropomorphic phantom to measure absorbed doses at specific organ sites. Thermoluminescent dosimeters (TLDs) are the most widely used dosimeters for such point dosimetry estimates.1 The most commonly used thermoluminescent material is lithium fluoride doped with magnesium and titanium and the characteristics of this material have been widely studied and are well established.1 When exposed to ionizing radiation, the dosimeter crystals absorb energy, producing free electrons, which become trapped in a metastable state at sites of imperfections in the crystal lattice structure. When heated, the trapped electrons return to their stable, ground state and the energy differential is released as visible light photons. The intensity of the emitted light is proportional to the absorbed energy, and, thus, serves as a measure of the absorbed radiation dose. TLDs offer several advantages. They are small in size making it convenient to place them on the body or at a specific site in a tissue-equivalent phantom. TLDs are resilient to environmental changes and are reusable. The dose response is linear over a wide range of absorbed doses, approximately 10 μGy to 1 Gy.2 Disadvantages are that the equipment for measuring the doses absorbed by TLDs is expensive and requires the use of nitrogen gas. Furthermore, calibration of the measurement system and the process to ensure consistent dose measurements, especially in the low dose range, are cumbersome. Before use, the dosimeters are annealed to remove trapped charges. Reproducibility of this annealing regimen is especially important to ensure accurate dosimetry.3

Optically stimulated luminescence dosimeters (OSLDs), composed of carbon-doped aluminum oxide, have been used for personnel dosimetry for more than a decade.4 The basic principles of dose measurement are similar to that of TLDs. Like TLDs, energy from the incident photons produces electrons that are trapped at sites of crystal imperfections; however, instead of heating, the dose readout is performed by controlled illu-
The doses can be read repeatedly with only a 0.05% decrease in signal intensity. Alternatively, illuminating the OSLD with a 150-W tungsten-halogen light will discharge more than 98% of the signal. Recently, Landauer, Inc. (Glenwood, IL) introduced the OSLD nanoDots: a commercially available OSL dosimeter for single-point radiation measurements. These dosimeters contain a disk of aluminum oxide encased in a small plastic sleeve (Fig. 1). OSL-based dosimeters offer several advantages over currently used TLDs for point dosimetry measurements. First, the dynamic range of OSLDs is $10^{-6}$ to 10 Gy, which is broader than that of TLDs. Unlike TLDs, the dosimeters do not require an annealing process to prepare the dosimeters for use. Dose readouts are quick and nondestructive, allowing for dose verification and analysis of total dose accumulation and for immediate reuse of the dosimeters. In contrast to TLD systems, instruments used to measure OSLD absorbed dose are small, and portable versions are available. Importantly, the commercially available OSL nanoDot dosimeters are provided with an engraved bar code that encodes the dosimeter sensitivity and a unique identification to allow for efficient and accurate tracking of dose.

Several studies have used TLD dosimeters to estimate the effective dose from maxillofacial radiographic examinations. Given the advantages of OSLDs, it is likely that their use for dosimetry of diagnostic and therapeutic radiation techniques will increase. In this study, we examined the suitability of the OSL nanoDot dosimeters for dosimetry of diagnostic maxillofacial radiographic examinations and compared their performance relative to the widely used TLD chips.

**MATERIAL AND METHODS**

**Dosimeters and readers**

OSL nanoDot dosimeters were purchased from Landauer, Inc. Following exposure, OSLD-absorbed doses were measured on a light photon counter (MicroStar InLight Reader, Landauer, Inc.). The readout was determined approximately 20 minutes after radiation exposure. The OSLD readers are calibrated for 80 kVp. To account for energy dependence of the dosimeter, correction factors were applied to the measured doses following the manufacturer’s instructions. The correction factors were 1.0 for a 70-kVp beam and 1.2 for a 120-kVp beam. TLD-100 chips were supplied and analyzed by Landauer, Inc. Exposed TLDs were analyzed within 36 hours after radiation exposure. OSLDs were exposed within 24 hours after radiation exposure. Radiation exposures measured with a calibrated ionization chamber (RadCal, Monrovia, CA) served as control. Ion chamber doses measured in mR were converted to mGy.

**Determination of the dose response for OSLD nanoDots**

To examine the relationship between radiation exposure and the measured doses, OSLD nanoDots and an ionization chamber were exposed to radiation from a dental x-ray unit (JB70, Progeny Dental). Exposure parameters were 70 kVp and 7 mA. The source film distance and the exposure times were varied to provide a dose range of 10 $\mu$Gy to approximately 4900 $\mu$Gy, as determined by the ionization chamber. Separate OSLD nanoDots were used for each exposure setting and 2 independent exposures were made for each setting.

**Determination of signal fading**

Two OSLD nanoDots were exposed to a 70-kVp x-ray beam. The absorbed doses from OSLD nanoDots were determined 20 minutes after exposure. The dosimeters were then stored at room temperature for 1 month and the absorbed dose was remeasured. Three sequential readings were made for each dosimeter.

**Determination of angular dependence**

OSLD nanoDots, TLDs, and an ionization chamber were used to measure the x-radiation dose from a dental x-ray unit (JB70, Progeny Dental). Exposure parameters were 70 kVp, 1.4 mA, and a source-dosimeter distance of 30 cm. Dosimeters were exposed at the following beam incident angles: 0°, 15°, 30°, 45°, 60°, 75°, and 90° (where 90° represents the angle at which the central ray of the x-ray beam is perpendicular to the largest surface area of the dosimeter). Separate OSLD
nanoDots were used for each exposure setting and 3 independent exposures were made for each dosimeter angle.

Cone beam computed tomography (CBCT) exposures were done on a Hitachi CB Mercuray Unit (Hitachi Medical Systems, Cleveland, OH). TLDs and OSLD nanoDots were placed at selected anatomic sites of a head and neck phantom (RANDO, The Phantom Laboratory, Salem, NY), as listed in Table I. The phantom was custom modified to accommodate the OSL nanoDot dosimeter. The phantom was exposed at 3 different fields of view (6 inches, 9 inches, and 12 inches) to yield a range of radiation doses. Exposure parameters were 120 kVp and 150 mA.

Statistical analysis
Statistical analyses were done using GraphPad Prizm 5.0d and InStat 3.1a software programs (GraphPad Software, Inc., La Jolla, CA). The relationships among doses measured by OSLD nanoDots, TLDs, and ionization chamber were analyzed using linear regression analysis and Spearman’s correlation. For studies examining the angular dependence of OSLD nanoDots and TLDs, we used 2-way analysis of variance to analyze the effects of the 2 nominal variables (dosimeter system and angle of incidence) on the measurement variable (measured dose).

RESULTS

Dose response of the OSLD nanoDots

We first compared the dose response of OSLD nanoDots. To simulate the low doses absorbed by tissues during intraoral or panoramic radiographic examinations, we examined this response over the range of approximately 10 to 4900 μGy. OSLD-measured doses closely matched the actual radiation dose, as determined by a calibrated ionization chamber (Fig. 2). There was a linear relationship and a strong correlation between the doses measured with the OSLD and the ionization chamber ($r^2 = 0.997$).

We next determined if there was any loss of the signal owing to storage of the dosimeter. OSLD nanoDots were exposed to x-radiation and the dose was read at 20 minutes and 4 weeks after exposure. There was no significant difference in the measured dose between the 2 time periods (Table II), suggesting minimal loss of the latent signal over time.

Angular dependence of OSLD nanoDots

Angular or directional dependence is variation in the response of a dosimeter with the angle of incident radiation. Depending on the magnitude of this variation, a dosimeter could potentially over- or underestimate the radiation dose. Thus, we examined directional

Table I. Doses from CBCT exposures measured by OSLD nanoDot dosimeters and TLD at specific anatomic locations in dosimetry phantom

<table>
<thead>
<tr>
<th>Examination/site</th>
<th>Absorbed dose, mGy</th>
<th>Variance in OSLD dose</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>OSLD</td>
<td>TLD</td>
</tr>
<tr>
<td>12-inch field of view</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left parotid</td>
<td>13.1</td>
<td>15.4</td>
</tr>
<tr>
<td>Pituitary fossa</td>
<td>7.5</td>
<td>8.7</td>
</tr>
<tr>
<td>Right calvarium</td>
<td>10.9</td>
<td>11.6</td>
</tr>
<tr>
<td>9-inch field of view</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left parotid</td>
<td>12.9</td>
<td>15.2</td>
</tr>
<tr>
<td>Pituitary fossa</td>
<td>6.6</td>
<td>7.6</td>
</tr>
<tr>
<td>Right calvarium</td>
<td>2.4</td>
<td>2.0</td>
</tr>
<tr>
<td>6-inch field of view</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left parotid</td>
<td>12.4</td>
<td>13.7</td>
</tr>
<tr>
<td>Pituitary fossa</td>
<td>2.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Right calvarium</td>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

CBCT, cone beam computed tomography; OSLD, optically stimulated luminescent dosimeter; TLD, thermoluminescent dosimeter.

Table II. Effect of dosimeter storage time on measured dose

<table>
<thead>
<tr>
<th>Time between exposure and dosimeter reading</th>
<th>Measured dose, μGy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dose 1</td>
</tr>
<tr>
<td>20 min</td>
<td>20.6 ± 0.7</td>
</tr>
<tr>
<td>4 wk</td>
<td>19.9 ± 0.7</td>
</tr>
</tbody>
</table>
dependence of OSLD nanoDots and compared these variations with TLD, the currently used point dosimeter for maxillofacial radiation dose estimates. Both dosimeter systems demonstrated a significant angular dependence ($P < .001$, Fig. 3). This variation ranged from 88% to 109% for the OSLD nanoDots and from 91% to 105% for the TLD. Overall, there was no significant difference in the magnitude of angular dependence between these 2 dosimeters. Notably, doses measured with the TLDs were slightly higher than the doses measured with the OSLD nanoDots, although overall this difference was not statistically significant.

To further examine the clinical significance of difference between the OSLD nanoDots and TLDs, we used both these dosimeters to measure the absorbed dose from CBCT examinations. Given the rotation of the x-ray beam in CBCT, measured doses will reflect both the sensitivity of the dosimeter system as well as the inherent angular dependence of the dosimeters. For this study, we evaluated the dose at 3 anatomical sites using 3 different CBCT examinations (Table I). Doses measured by the 2 dosimeters differed: OSLD nanoDot measured doses ranged from 15% lower to 20% higher than the corresponding TLD dose (Table I). Nevertheless, there was a linear relationship and a strong correlation between the doses measured with the OSLD and TLD systems ($r^2 = 0.99$, Fig. 4).

**DISCUSSION**

Estimation of effective doses from radiographic examination is essential to developing selection criteria for radiological imaging, based on the risk-benefit analysis of the procedure. Typically, these dose estimations are done using TLDs to measure the absorbed dose at various anatomic locations in an anthropomorphometric phantom. Recently, OSLD nanoDots, a commercially available radiation dosimeter system, was introduced as a convenient alternative to TLD for point dosimetry. This dosimetry system offers several advantages over currently used TLD chips. Most importantly, the equipment required to read these dosimeters is smaller and often portable. Unlike equipment used to read TLD chips, OSLD readers do not require extensive calibrations or the use of nitrogen gas.

Several studies have used TLD dosimeters to estimate the effective dose from maxillofacial radiographic examinations.6-12 In all of these studies, dose measurements were made using TLD systems. Recently, Lanauer, Inc., a major provider of TLD services, indicated that it would begin to phase out such TLD services. Given its convenience, it is likely that OSLD systems will replace TLD systems for point dosimetry applications. Indeed, manufacturers of dosimetry phantoms have also introduced adapters to allow use of the OSLD nanoDots in currently used anthropomorphometric phantoms. As future studies are likely to use the OSLD system, it is important to establish whether changes to the dosimetric system will result in changes to our current dose estimates. This is especially important when new studies using OSLD systems compare dose estimates to existing data that are based on TLD measurement. Here we report on the suitability of OSLD nanoDots for maxillofacial radiation dosimetry.
We evaluated the dose response of OSLD nanoDots over the dose range of 10 to 4900 μGy, which encompasses the range of absorbed doses from intraoral, panoramic and cephalometric radiographic examinations. We found that the OSLD dose response is linear over this dose range and correlated significantly with the actual delivered dose, as determined using an ionization chamber (Fig. 2). Our data are consistent with previous reports that demonstrate a linear dose relation for OSLD dosimeters over the range of 10 μGy to 10 Gy. Thus, the OSLD is a robust system that can accurately measure doses, even over the low dose range in dental radiographic examinations. Typically, when using TLDs, the radiographic phantom containing the dosimeters is exposed 2 to 3 times to yield a dose that is high enough to be reliably measured. In contrast, even doses as low as 10 μGy were reliably measured from a single exposure using the OSLD nanoDots, underscoring its higher radiation sensitivity. We also observed a minimal loss of latent signal over time for doses in the range of 20 to 25 μGy. Whether higher doses result in more signal fading remains to be determined.

Importantly, there was a linear relationship and a strong correlation between the doses measured by the OSLD nanoDots and the TLDs (Fig. 4, Table I). There was some discrepancy between the systems, with the OSLD measured dose ranging from 15% lower to 20% higher than the corresponding TLD dose. However, the magnitude of this variation is not clinically significant. This variation is within the range of differences in reported dose estimates from different groups for the same procedure on the same radiographic unit. Furthermore, such effective dose measurements serve as an estimate, and not as a precise indicator of the dose that will be received by individual patients. Thus, we can reliably compare future OSLD-based dose estimates with current TLD-based measurements. We also evaluated the angular dependence of the OSL dosimeters. Similar to TLDs, OSLD nanoDots also show angular dependence; however, the magnitude of this angular dependence was not significantly different between these 2 dosimeter systems (Fig. 3), further highlighting the concordance in dose measurements between OSLD- and TLD-based dosimeters.

In summary, we demonstrate the OSL nanoDot dosimetry system is well suited for radiation dose measurements from maxillofacial radiographic examinations. Based on our data, we anticipate that these dosimeters will perform as well as currently used TLD chips. Future studies on effective dose estimates using this new system should not differ significantly from current TLD-based dose estimates.

REFERENCES

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