

Radiosurgery dosimetry using CaSO₄:Eu OSLD film—a feasibility study

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Abstract

Recent studies demonstrated that optically stimulated luminescence (OSL) systems allow the evaluation of doses for 2D mapping in a relatively fast and simple way and results show submillimeter resolution. This work presents, for the first time, an optically stimulated luminescence dosimeter (OSLD) in the form of film made with CaSO₄:Eu particles embedded in a silicone elastomer matrix. The OSLD film was produced using a low-cost and relatively simple methodology. This film is reusable and the signal can be satisfactorily bleached using blue LEDs. The main dosimetric properties were evaluated using TL/OSL Risø reader with blue stimulation and Hoya U-340 filter. Investigation shows repeatability within 3% when measuring with the same film sample. Regarding the OSLD film homogeneity, nearly 12% sensitivity change was observed within the 5 × 5 cm² produced film. Additionally, the dose response curve shows linearity from 5 to 25 Gy. Fading of the OSL signal is relatively high, about 50% in the first week and then is stable. Nevertheless, a 3 × 3 cm² OSLD film was successfully used to map dose distribution in radiosurgery (6 MV photon beam). This work demonstrates the feasibility of 2D dosimetry using reusable OSLD films based on CaSO₄:Eu.

In modern radiotherapy (RT) treatments, the small fields and complex dose distributions require adequate and precise dosimetry techniques. Currently, the protocols for quality assurance (QA) and performance tests in radiology and RT employ detectors in film-shaped or two-dimensional (2D) detector arrangements^(1, 2). Detector arrays can use ionisation chambers, thermoluminescence (TL) detectors or silicon diode detectors, and others. The arrangements present limited spatial resolution and data acquisition is time consuming because of the use of several detectors in specific positions⁽³⁾. Radiological and radiochromic films are practical and have a high spatial resolution, which is essential for the verification of accented dose gradients. Radiochromic films have the advantage of being insensitive to ambient light and do not require chemical processing. Also, these have little or no energy dependence in RT beams. However, there is dose rate dependence and the quantification of response variation depends on calibration, and the films are not reusable⁽⁴⁾. It requires calibration to be performed with one film and measurements with others so that the accuracy of the

result is dependent on the variability of the production of the films. In addition, these films are commercially available at an exceedingly high cost, particularly in developing countries. Detectors based on the optically stimulated luminescence (OSL) technique often have the advantage of detector reusability. Thus, in principle, optically stimulated luminescence dosimeter (OSLD) films can be easily acquired (at a relatively low cost) and reusable.

Recent studies in the literature have presented OSL systems that allow the evaluation of doses for 2D mapping relatively quickly and simply, because of optical stimulation, and results with a submillimeter resolution, mainly for applications in RT^(5–7).

Although the OSL technique has several advantages for 2D mapping, to the best of our knowledge, there is no commercial OSLD film available to be used in dosimetry, especially in small fields such as radiosurgery.

Calcium sulfate (CaSO₄) with different types of dopants is well characterised and widely used with the TL technique, especially CaSO₄:Dy produced at

IPEN in Brazil⁽⁸⁾. Depending on the dopant or impurity introduced into its crystal lattice, this material can also present an OSL signal with advantageous dosimetric properties for its application with the OSL technique⁽⁹⁾.

Considering the advantages of the OSL technique in dosimetry and the low number of commercial detectors available, the main objective of this work was to produce and characterise OSL detectors in the form of flexible foils (OSLD films) and to test the feasibility of applying these OSLD films for dose mapping in radiosurgery. Films were produced using a low-cost, flexible matrix material and noncommercial detector material, CaSO₄:Eu.

Materials and methods

Production of OSLD film

For fabrication of OSLD film, two components were used: CaSO₄:Eu (in powder form) as the detector material and silicone rubber (model T2 from Dow Corning) as the film matrix.

Europium-doped CaSO₄ was produced at IPEN by the crystal growth slow evaporation route⁽¹⁰⁾. The T2 silicone rubber is sold as a rubber component plus liquid catalyst (preparation ratio is 10% of catalyst mass to the mass of the rubber), with a curing time of 24 h at room temperature. It is colorless and supports up to 190°C when cured, as specified by the manufacturer. This material was chosen as a film matrix because it did not present OSL signal and no mechanical damage was observed after exposure with accumulated doses over 60 Gy.

Before the production of the films, CaSO₄:Eu powder was submitted to thermal treatment (300°C for 60 min), to erase spurious OSL signal storage in the material. In this work, the OSLD film was produced with 20% in mass of CaSO₄:Eu. Silicone and detector powder were mixed slowly, always in the same direction, for 5 min.

Then the catalyst was added, and it was mixed slowly for 2 min and the mixture was poured into a square mold. Immediately, a bubble-pick roller was passed back and forth in both directions of the form. It was covered and left untouched for 24 h. After this period, the OSLD film was de-molded. An extra period of 7 d was allowed before using the film.

Dosimetric properties of the OSLD films

To evaluate the dosimetric properties of OSLD films, one of them was cut into 5 × 5 mm² samples. These samples were irradiated and read on an automated TL/OSL Risø reader, which is equipped with blue LEDs for stimulation, a built-in beta source (⁹⁰Sr/⁹⁰Y), resulting in a dose rate at the sample position of

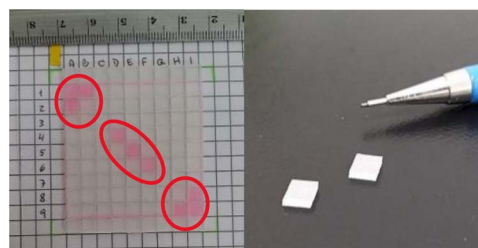


Figure 1. (a) Three regions (marked in red) of the OSLD film with three samples in each, and (b) two of the samples.

0.08 Gy/s, and a Hoya U-340 filter in front of photomultiplier tube for detection of OSL signal. Irradiations and OSL readouts were performed at room temperature.

Repeatability

To evaluate the repeatability of the response of the OSLD films, nine samples were used. An absorbed dose of 3 Gy was adopted for irradiations with Risø's built-in source and a stimulation time of 1800 s in the reader. Three cycles of irradiation and readout were performed.

Homogeneity of the OSLD film

The film homogeneity was evaluated in terms of sensitivity. Three groups of samples were purposely taken from three different regions of the OSLD film, as shown in Figure 1.

The samples were irradiated with a dose of 3 Gy each and were read with optical stimulation of 10 s.

OSLD film signal fading

The dark storage fading of the OSL signal was evaluated using five samples of the OSLD film. To avoid the influence of sensitivity variation from one sample to another, the same five samples were used for all measurements. The OSL signal after different periods was always compared with the OSL signal of the same sample, read immediately after irradiation (named time zero).

The samples were first irradiated (20 Gy) and read, in the Risø reader, right after irradiation, one at a time, to obtain the OSL signal of each sample (Zero). Then, the samples were irradiated in the Risø reader, removed and kept in the dark for the established period, and then replaced in the reader to obtain the OSL signal after the established periods. This was repeated for each fading period studied: 10 min, 30 min, 1 h, 24 h, 2 d, 1 week, 2 weeks and 3 weeks. Between each of these cycles, samples were bleached for 7 h to ensure cleaning of residual OSL signal. Furthermore, the background signal (BG) was verified before each irradiation.

The percentage of fading of the OSL signal was obtained for different periods, for each one of the five samples.

Dose response of the OSLD film

To obtain the response of the OSLD film as a function of the dose, 24 samples were used. Three samples were used for each absorbed dose. All of them were irradiated on the same day in the Risø reader and then stored for 2 weeks, protected from light and radiation sources, to minimise the influence of fading.

After 2 weeks, the OSL signal of the samples were stimulated for 180 s, then bleached. Finally, the samples were returned to the reader for irradiation, all with a reference dose (5 Gy) and OSL reading, one at a time.

Thus, the dose–response was corrected for the sensitivity of the samples. This methodology was adopted because, due to the limited amount of OSLD films, it was not possible to perform a previous selection of detectors by sensitivity.

Optical treatment for OSLD film reuse

A bleaching device was developed for the optical treatment of the OSLD films. It is a polished aluminum can with a 10 W blue LED lamp PAR30 (Lexman). Film samples previously irradiated with absorbed doses of 5–25 Gy were treated for 7 h inside the can, positioned 12 cm distant from the lamp.

Feasibility of application of OSLD film in radiosurgery dosimetry

To evaluate the possibility of applying OSLD films in radiosurgery, samples of the OSLD films produced were sent for irradiation at Clinirad—Radiotherapy and Quimiotherapy Clinic Headquarters Curitiba—Halsted Institute (Brazil).

Sample preparation

Using a grid pattern, ruler and scalpel, strips of 2 cm long and 0.5 cm wide OSLD film and a 3 × 3 cm² sample were cut. Four strips were separated for calibration and one for BG control. In addition, a sample of 3 × 3 cm² was irradiated in a simulated radiosurgery treatment. All these samples were new and were previously optically treated. Then they were packed one by one, in packages with black electrical tape, completely sealed from exposure to light. Each package was identified before being sent to the clinic, as shown in [Figure 2](#).

Irradiations

In the clinic, the linear accelerator used was the Synergy Full model (Elekta) with options for photon and electron beams of different energies. In this work, only the 6 MV photon beam was used.

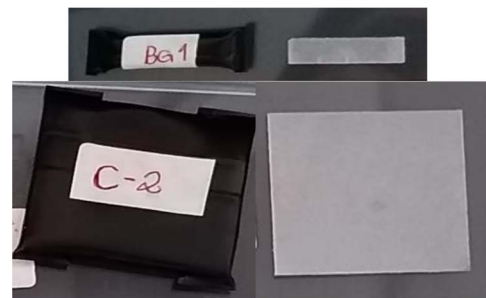


Figure 2. On the right side, an example of two samples of OSLD film sent for irradiation in a clinical linear accelerator. On the left, the same samples were packed protected from light exposure. Above, one of the OSLD film strips (2 × 0.5 cm²), and below, is a 3 × 3 cm² sample.

All irradiations were performed on the same day and, to guarantee the reliability of the measurements, also a set of QA tests was first carried out in the linear accelerator, as recommended by TECDOC 1151⁽¹¹⁾. Both mechanical and dosimetric tests were carried out (described in TRS 398⁽¹²⁾).

After the linear accelerator validation, the OSLD film samples were irradiated in a phantom. It was mounted with polymethylmethacrylate plates with density equivalent to water. Sixteen 1 cm thick plates and two 0.5 cm thick plates were used to form a simulator of dimensions 30 × 30 × 17 cm³, which meets the recommendations of Report TG 119⁽¹³⁾. These plates already have a crease in the central region for fitting the ionisation chamber. For the irradiations of the OSL samples, the central plate was replaced by two layers of bolus gel, to embrace the OSLD film and minimise the air layer between the film and the plates.

First, four strips of OSLD film were irradiated in a 6 MV photon beam, each with a planning dose. The doses used were 5, 10, 20 and 30 Gy, for the evaluation of the calibration factor and the dose response of the OSLD film in clinical conditions.

Then, the 3 × 3 cm² OSLD film sample was irradiated to verify the dose distribution in the radiosurgical planning. 21 Gy was adopted because it is the usual dose in radiosurgery treatments in the clinic.

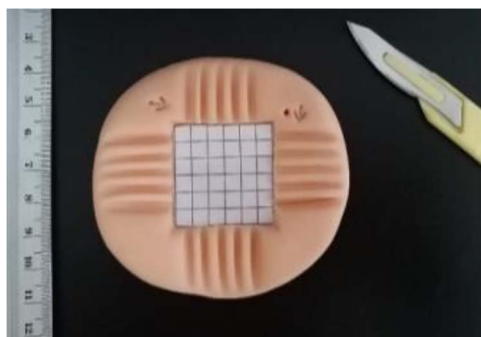
OSL readout

The irradiated samples were stored for 2 weeks protected from light, to wait for the stabilisation of the OSL signal fading, and then, the OSL signals were read in the Risø reader. For this, as this reader is designed for spot readings, the OSLD films were cut in 36 pieces.

The packages were opened in the dark, with only a red lamp positioned indirectly, in the OSL reader laboratory. The OSLD films were cut in biscuit molds, specially designed for this task, ([Figure 3](#)). The samples were cut using a ruler (positioned in the corresponding creases of the mold) and a scalpel.

Table 1. Average initial OSL intensity and the respective coefficient of variation obtained from three cycles of irradiation and OSL readout.

OSLD film sample	Average initial OSL intensity (counts)	Coefficient of variation (%)
1	13 790 ± 353	2.6
2	15 102 ± 152	1.0
3	13 862 ± 298	2.1
4	16 634 ± 330	2.0
5	17 838 ± 324	1.8
6	16 342 ± 112	0.7
7	17 641 ± 335	1.9
8	16 312 ± 311	1.9
9	22 339 ± 162	0.7

**Figure 3.** OSLD film cutting mold.

The OSL signal of each sample was stimulated and recorded for 180 s. After reading all samples, they were optically treated to clean all the OSL signals. Subsequently, they were again taken to the reader, in the respective cups, and in the same positions. Then they were irradiated (reference dose) and their OSL signals were read (for 180 s) immediately after irradiation. This was performed one sample at a time, using the reader source and a dose of 5 Gy.

In the analysis of the results, the OSL intensity measurements obtained from the clinical irradiations were divided by the OSL intensity measurements after the reference dose. This procedure was adopted to correct differences in mass and sensitivity from one OSLD film sample to another.

Results and discussion

OSLD film

The OSLD film produced measures $60 \times 60 \times 1.5 \text{ mm}^3$.

Dosimetric properties of the OSLD films

Repeatability

To evaluate the repeatability, nine samples were used and each one was irradiated and read three times. Table 1 lists, for each sample, the average initial OSL

intensity of the three cycles and the respective coefficient of variation.

The maximum coefficient of variation (evaluated through the ratio between uncertainty and average value) to the average value was 2.6%, thus the OSLD film presents satisfactory repeatability.

Homogeneity of the OSLD film

Table 2 presents the average initial OSL intensity of each region of the OSLD film for the homogeneity test.

In each of the three regions, the variation in OSL sensitivity is around 5%.

On the other hand, comparing the three regions, a coefficient of variation of 12% was obtained.

Because of this difference in sensitivity between samples of the same film, it was decided to correct the results of this work (presented below) by the sensitivity of each OSLD film sample.

Dose response of the OSLD film

The response of the OSLD film as a function of absorbed dose is shown in Figure 4. Each data point is the average initial OSL intensity (corrected by sensitivity) of three samples.

Results show that the OSLD film responds linearly to a dose in the range of 5–25 Gy. The *R*-square value confirms linearity in that range.

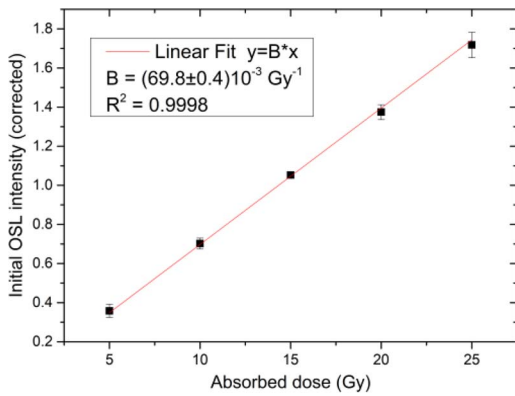
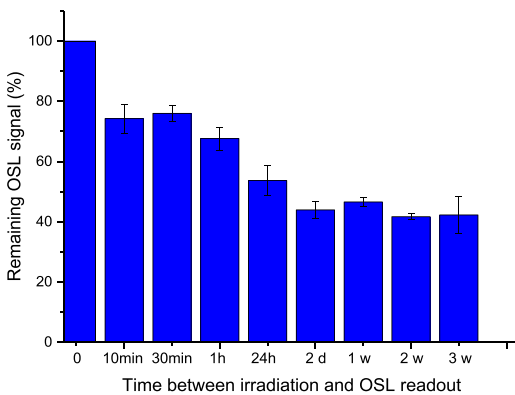
Fading of the OSL signal

The result of the OSL signal fading during dark storage was calculated by the average remaining signal (five samples) and its standard deviation for each period (10 min, 30 min, 1 h, 24 h, 2 d, 1 week, 2 weeks and 3 weeks). The initial OSL intensity was used (Figure 5).

The results demonstrate that in the first 24 h there is a significant loss of the OSL signal and this fading of the OSL signal stabilises 2 d after irradiation.

Table 2. Average initial OSL intensity and the respective coefficient of variation of each film region.

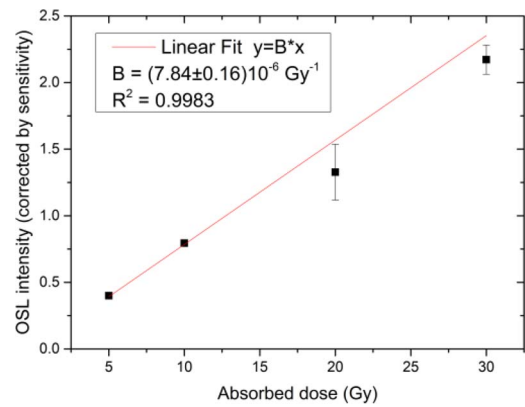
OSLD film region	Average initial OSL intensity (counts)	Coefficient of variation (%)
1	14 251 ± 737	5.2
2	16 938 ± 793	4.7
3	17 968 ± 747	4.2

**Figure 4.** OSLD film response as a function of dose. Each data point corresponds to the average initial OSL intensity of the samples (corrected by sensitivity) and the error bars are the average standard deviation. The label presents the linear fitting parameters.**Figure 5.** Remaining OSL signal after different time periods (10 and 30 min, 1 and 24 h, 2 d and 1, 2 and 3 weeks) obtained from average initial OSL intensities of five samples. Error bars are the average standard deviation.

Feasibility of application of OSLD film in radiosurgery dosimetry

Calibration of the OSLD film in the clinical beam

Calibration of the OSLD film was performed under clinical conditions in a 6 MV photon beam. [Figure 6](#) shows the dose response of OSLD films. The initial OSL intensity was corrected for the sensitivity of each OSLD

**Figure 6.** Calibration curve of OSLD film response as a function of dose obtained in clinical irradiations (6 MV photons).

film sample and the points represent the average value of four samples.

2D dose distribution

A 3×3 cm² OSLD film sample was irradiated in the center of the phantom with a planned dose of 21 Gy. This film was cut into 36 samples and the initial OSL intensity of each one was obtained and was corrected by sensitivity. This value was converted into absorbed dose (Gy), using the previous calibration ([Figure 6](#)).

[Figure 7](#) shows the gray scale dose map obtained.

The dose levels measured with OSLD film ([Figure 7](#)) are compatible with the dose distribution showed by the treatment planning system ([Figure 8](#)). Using the OSLD film, we observed the value of the planned dose of 21 Gy ([Figure 8](#)), and the hot spots (doses higher than the planned dose) are ranging up to 29 Gy. [Figure 8](#), obtained from treatment planning system, shows hot spots up to ~30 Gy. The values obtained in QA with both ionisation chamber (22.9 ± 0.5 Gy) and OSLD film (doses ranging from 22.5 Gy up to 23.4 are showed at 2D dose map in [Figure 7](#)) agree with planned dose presented by the dose distribution from treatment planning system.

The result obtained demonstrates that it is possible to use the OSLD films proposed in this work to verify the dose distribution of radiosurgery planning. ‘Valleys’

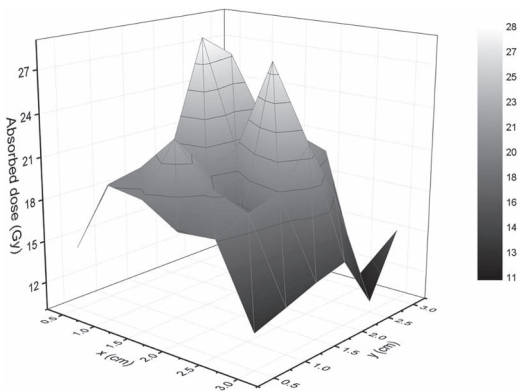


Figure 7. 2D dose map of a radiosurgery treatment obtained with OSLD film irradiated in a phantom.

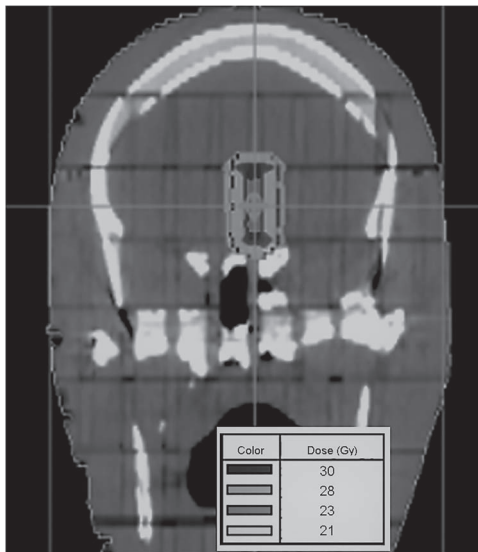


Figure 8. Radiosurgery treatment planning dose distribution.

were observed at Figure 7 because the OSLD film was cut to be read at the Risø reader and, most likely, the cut occurred in these areas causing the dose ‘valleys’.

Conclusion

A relatively simple methodology for producing OSLD films in laboratory was developed, using T2 Dow Corning silicone rubber and CaSO₄:Eu powder. The OSLD film is a financially accessible alternative when compared with commercially available OSL detectors.

The dosimetric properties of the OSLD films showed repeatability of <3% and linearity for the dose range from 5 to 25 Gy. Although the fading of the OSL signal is high in the first 24 h, the results show that it is stable after 2 d of irradiation.

The applicability of OSLD films in clinical dosimetry was tested in RT with small fields in radiosurgery treatments. It was verified that it is possible to calibrate the film and perform 2D mapping of radiation treatment doses. In this preliminary assessment, the OSLD film needed to be cut; however, there are already studies proposing OSL readers made in the laboratory for 2D OSL reading which, in principle, can be reproduced and used to read the OSLD film proposed in this work. Moreover, the produced films are easy to handle and can be reusable, even with high doses such as in RT treatments. It could be a practical and precise option for routine QA dosimetry in RT.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

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