Flexible film dosimeter for in vivo dosimetry

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INTRODUCTION

- When tumors are located on the skin or at superficial regions near the skin, the prescribed doses cannot be delivered to the whole volume of the tumors with high-energy photon beams owing to electronic disequilibrium.
- Therefore, to increase doses deposited to the patient's superficial regions, layers capable of increasing the electron fluence, such as boluses, wax, or three-dimensional printed devices, should be placed on the skin.
- When applying boluses to patients' irregular surfaces, such as scalp, breast, perineum, and foot, there might be discrepancies in the setup of the boluses with respect to the treatment plans and the actual deliveries of the plans, which is undesirable.
- In such cases, in vivo dosimetry is performed to verify accurate delivery of the treatment plans to patients.
- For in vivo dosimetry, various dosimeters, such as a thermoluminescent dosimeter (TLD), optically stimulated luminescent dosimeter (OSLD), metal oxide semiconductor field-effect transistor (MOSFET), or GAFCHROMIC EBT3 radiochromic films (EBT3), are currently used in the clinical setting. However, these dosimeters are not flexible enough to apply to irregular surfaces.
- The aims of this study were to develop a flexible film dosimeter applicable to the irregular surface of a patient for in vivo dosimetry and to evaluate the device's dosimetric characteristics.

METHOD

- A flexible film dosimeter with active layers consisting of radiochromic-sensitive films and flexible silicone materials was constructed as shown in Figure 1.
- It was fabricated with silicone, the lithium salt of pentacosa-10, 12-diyonic acid (LiPCDA).
- The dose-response, sensitivity, scanning orientation dependence, energy dependence, and dose rate dependence of the flexible film dosimeter were tested.
- Irradiated dosimeters were scanned 24 h post-irradiation, and the region of interest was 5 mm × 5 mm.
- The dose uncertainty was calculated using a propagation of error analysis developed by Devic et al.[1)]
- Biological stability tests ensured the safety of application of the flexible film dosimeter for patients.
- A preliminary clinical study with the flexible film dosimeter was implemented on four patients.

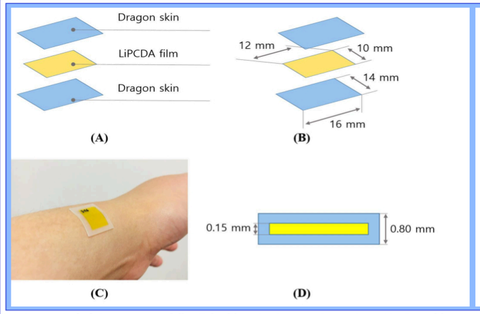

Figure 1. (A) Structure of flexible film dosimeter based on LiPCDA film, (B) dimensions of flexible film dosimeter, (C) flexible film dosimeter attached to a wrist, and (D) cross section of flexible film dosimeter.

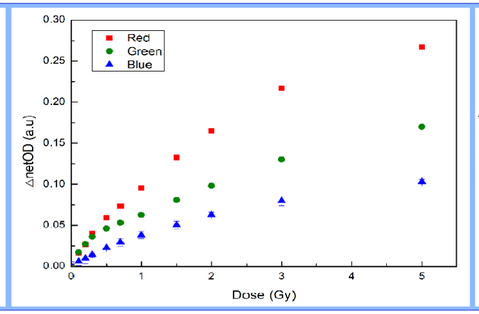

Figure 2. Dose-response of the flexible film dosimeter in the RGB channels.

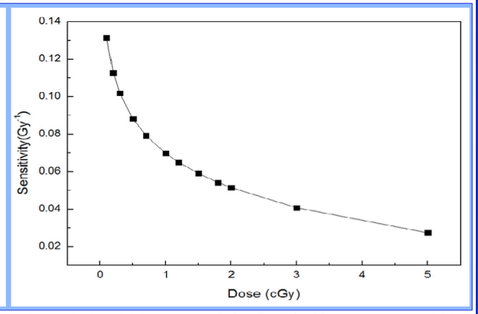

Figure 3. Sensitivity curve of the flexible film dosimeter within the range of 0 to 5 Gy.

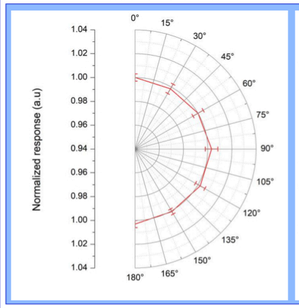

Figure 4. Scanning orientation dependence of the flexible film dosimeter.

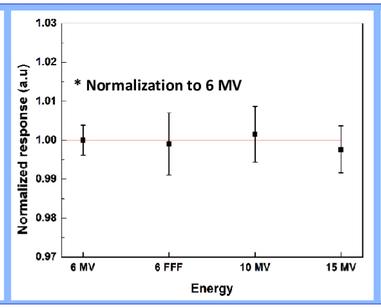

Figure 5. Energy dependence of the flexible film dosimeter.

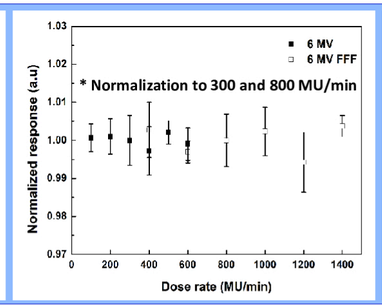

Figure 6. Dose rate dependence of the flexible film dosimeter.

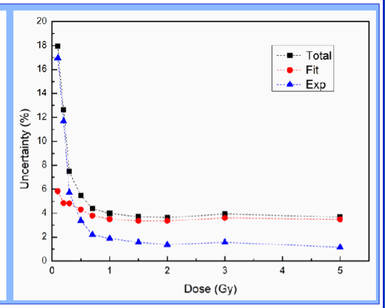

Figure. 7. Dose uncertainty of the flexible film dosimeter.

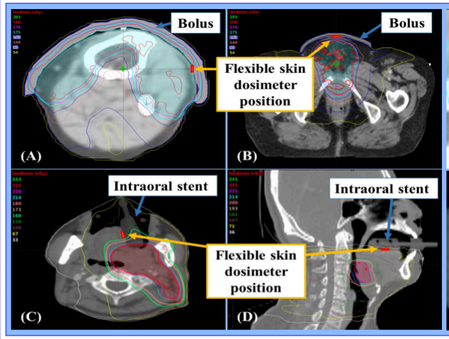

Figure 8. Bolus and in-house intraoral stent used clinically on the (a) knee, (b) vulva, (c) tonsils, and (d) oropharynx of all four patients.

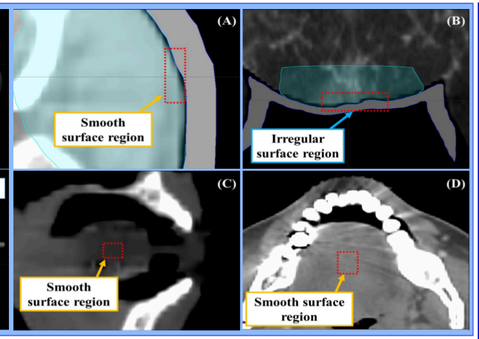

Figure 9. Region of flexible film dosimeter attached to irregular and smooth surfaces of the (a) knee, (b) vulva, (c) tonsils, and (d) oropharynx of the four patients.

TABLE I. Clinical study data for the flexible film dosimeter. For each patient, doses were measured three times.

	Patient 1	Patient 2	Patient 3	Patient 4
Site	Knee	Vulva	Tonsils	Oropharynx
Calculated (cGy)	182.4	181.9	135.3	86.7
Measured (cGy)	180.2 ± 4.0	182.1 ± 3.5	134.9 ± 0.7	85.7 ± 3.6
% Difference (%)	1.2 ± 2.2	−0.1 ± 1.9	0.7 ± 0.1	1.2 ± 4.2
Uncertainty (%)	4.0	3.7	4.1	4.3

RESULTS

- The red channel demonstrated the highest sensitivity among all channels in Figure 2, and the response sensitivity of the dosimeter decreased with the applied dose in Figure 3.
- The dosimeter responses at various scanning orientations showed differences of <1.0% from each other in Figure 4.
- As shown in Figure 5, the flexible film dosimeter showed no significant energy dependence for photon beams of 6 MV, 6 MV flattening filter-free (FFF), 10 MV, and 15 MV. The flexible film dosimeter showed no substantial dose rate dependence with 6 MV or 6 MV FFF in Figure 6.
- For doses within the range of 1–5 Gy, the total uncertainties of the flexible film dosimeter measurements were lower than 4.0% in Figure 7.
- In terms of biological stability, the flexible film dosimeter demonstrated no cytotoxicity, no irritation, and no skin sensitization.
- Figure 8 and 9 show the positions of the flexible film dosimeters adhered to both irregular and smooth surfaces using boluses and an in-house intraoral stent for the four patients at the knee, vulva, tonsils, and oropharynx.
- In the preliminary clinical study, the dose differences between the measurements with the flexible film dosimeter and calculations with the treatment planning system ranged from –0.1% to 1.2% for all patients in Table 1. The uncertainties in the measurements with the flexible film dosimeters for patients 1, 2, 3, and 4 were 4.0%, 3.7%, 4.1%, and 4.3%, respectively, which are similar to those shown in Fig. 7.

CONCLUSIONS

The dosimeter developed in this study is a flexible film capable of attachment to a curved skin surface. The biological test results indicate the stability of the flexible film dosimeter. The preliminary clinical study showed that the flexible film dosimeter can be successfully applied as an in vivo dosimeter.

ACKNOWLEDGEMENTS

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