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Out-of-Field Dosimetry in IMRT with OSL

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Abstract. *Introduction:* Accurate radiation dose measurements at non-target tissues in external beam radiation oncology treatments has become a relevant issue in modern clinical practice. In these cases, low doses out-of-the-treatment-field (OTF) were considered those less than 20% of the prescribed dose beyond 1 cm from field edge defined by jaws. In this work we compare dosimetric response of the optically stimulated luminescence dosimeter OSLD nanoDot versus ionization chamber (IC) and treatment planning system (TPS) Modular Integrated Radiotherapy System (MIRS) v.5.1 and Eclipse (AAA) in cases of water phantom, anthropomorphic phantom CIRS and *in vivo* tests on points OTF in IMRT with compensator filters. *Method:* I) in a water tank phantom using 6 MV photon beam (Varian Clinac iX). Exposures were carried out with open field and adding a scatter element (cerrobend compensator filter) at 2.5, 4.5 and 6.5 cm from field edge. II) in anthropomorphic thorax CIRS phantom for an IMRT plan with compensator filters, measurements were made at 4 cm OTF. III) in IMRT plans for 20 intracavitary *in vivo* dosimetry (IVD) measurements were carried out (on average 9 cm distance OTF). Dosimeters were placed in the oral cavity and rectum. *Results:* I) In water phantom, OSL response closely followed the IC measured dose: absolute difference of 2.6% in open field and 4.4% with presence of scatter element up to 6.5 cm OTF. Absolute differences showed that both TPS MIRS and Eclipse underestimated doses up to 55.7% and 39.4% respectively in presence of scatter elements up to 6.5 cm from field edge. II) In anthropomorphic phantom, in terms of absolute differences, OSL measured dose followed IC up to 3%. TPS MIRS underestimated doses up to 34.5%. III) intracavitary *in vivo* dosimetry measurements for OSL and TPS MIRS showed absolute difference dose underestimation up to 42%. *Conclusions:* Different experiments showed a reliable response of OSL nanoDot versus IC. Both TPS MIRS and Eclipse (AAA) show limitations to determine and to model OTF dose with differences up to 55.7%. Multiple tests has shown OSLD nanoDot with a correct and adequate low dose calibration curve is a viable detector to measure OTF dose since there is no need for correction factors for spectral changes as suggested by Bordy *et al*. It is important to continue researching dosimetry in anatomical regions at OTF low doses due to probable long-term biological effects.

Keywords: OSL, out-of-field dosimetry, low dose, IMRT.

INTRODUCTION

Accurate radiation dose measurement at non-target tissues in external beam radiation oncology treatments has become a relevant issue in modern clinical practice. In these cases, doses are less than 20% the prescribed dose to planning target volume (PTV). Huang et al. [1] showed dose underestimation by 50% in out-of-treatment-field (OTF) doses measured with thermoluminescent dosimeters (TLD). Howell et al. [2] showed dose underestimation by 40% by Eclipse's Analytical Anisotropic Algorithm (AAA) using TLD. In this work we compare dosimetric response of the optically stimulated luminescence dosimeter (OSLD) nanoDot versus ionization chamber (IC) and treatment planning system (TPS) Modular Integrated Radiotherapy System (MIRS) v.5.1 and Eclipse's AAA in cases of water phantom, anthropomorphic phantom CIRS and intracavitary *in vivo* dosimetry (IVD) measurements.

METHOD

OSLD nanoDot (10 × 10 × 2 mm³) manufactured by Landauer Inc. (Glendwood, USA) were prepared following TG-191 AAPM international guideline [3]. Dosimeters were read 24 h after exposure in MicroStar reader (Landauer Inc.). Dosimeters were read three times. After readout, dosimeters were bleached for 24 h with

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an 40 W halogen lamp.

A linear model of calibration curve was obtained directly in 6 MV beam (Varian Clinac iX) for low-doses (5 to 100 cGy). The measured dose with Farmer NE-2571 ionization chamber (IC) following IAEA TRS 398 [4] was compared with OSLD measurement. Calibration at these conditions and a rigorous dosimetry protocol allowed to neglect energy, fading and depletion factors. TG-191 AAPM [3] established the equation 1 that provides the dose D at a point for the average measurement after irradiation (M_{raw}) from OSLD:

$$D = k_s \cdot (M_{raw} - M_{bkg}) \cdot N_{D,W} \tag{1}$$

Where $N_{D,W}$ is the calibration coefficient, k_s is the sensitive factor, M_{bkg} is the background measurement.

Water Phantom Test

OSLD nanoDot response OTF was evaluated. Dosimeters were placed inside the water phantom with an acrylic pipette (to prevent the detector will get wet). They were exposed (SSD 100 cm, depth 10 cm, field size 10 × 10 cm²) and placed at 0, 7, 9 and 12 cm relative to the beam central axis. Two tests were carried out: with open field and with the field blocked by a scatter element (compensator filter, cerrobend, 1 half value layer). Dose was normalized to the dose measured by the dosimeter placed at the beam central axis. Values were compared with doses obtained by IC Farmer NE-2571 and TPS MIRS and Eclipse at the same irradiation conditions using two detectors for each position.

Anthropomorphic Test

IMRT with compensator filters treatment case was planned in TPS MIRS for CIRS thorax anthropomorphic phantom (002LFC model). The treatment plan was applied by moving the isocenter 9 cm in longitudinal direction. This ensured that OSLD (positioned in structure a in Fig. 1) was located at 4 cm outside the field edge defined by jaws. Measured dose was compared with doses obtained by IC and TPS MIRS at the same point where the OSLD was placed.

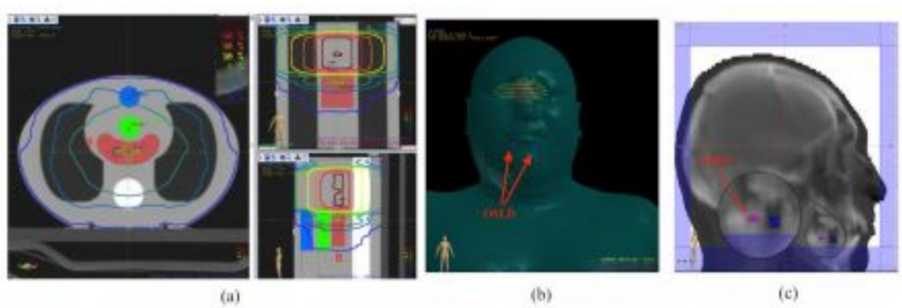

FIGURE 1. (a) Treatment plan applied in CIRS phantom to evaluate low dose OTF. b) OSLD intracavitary IVD in oral cavity location at TPS MIRS. c) OSLD location at digital reconstructed radiograph.

In vivo Test

The proposal for the study was approved by the research and ethics committee (Comité de Ética en Investigación en Salud) of the Regional Integration Oncology Center Foundation (Fundación Centro Oncológico de Integración Regional, Mendoza, Argentina). Inclusion criteria were patients with head-and-neck cancer and retroperitoneal tumor treated with IMRT using compensator filters. 10 patients (2 dosimeters per patient): 2 cases of rectum and 8 cases of oral cavity as organs at risk (OARs) participated in this statistical study. OTF dose was considered low when less than 20% of the prescribed dose beyond 1 cm from field edge as defined by jaws.

A small ergonomic silicone device was placed by one of the physicians. Anesthesia was not to be required. Silicone devices may contain two dosimeters and two radiopaque markers. Anteroposterior and lateral planar digital image was acquired before and after treatment respectively. Geometrical coordinates of the dosimeters were obtained by planar digital images using eFilm software. Geometrical coordinates were imported to TPS MIRS (Fig. 1.c). A small volume with dosimeter dimensions was constructed (Fig. 1.b). Calculated dose by TPS was assigned as the average dose at that volume. Calculated and measured doses were compared by absolute difference as $(D_{detector} - D_{IC})\times100/D_{IC}$ and relative difference as $(D_{detector} - D_{IC}) \times 100/D_{prescribed}$ following Van Dyk´s criteria [5].

RESULTS AND DISCUSSION

Figure 2 shows normalized OTF doses to beam central axis dose for OSL, IC, TPS MIRS and Eclipse in open field and field blocked by scatter element. From Fig. 2 it is noticeable that for both cases OSLD response followed with good agreement IC response with absolute difference of 2.6% in open field and 4.4% with presence of scatter element up to 6.5 cm OTF. At distances lower than 10 cm, OSLD calculated dose with a correct and adequate dose calibration curve does not need correction factors for spectral changes as suggested by some authors [6] where they found that a correction to decrease of dose is required when distances greater than 30 cm to the beam central axis due to the absorption of the scattered component of the radiation field in the water as the distance from the beam axis increases [6]. TPS calculated doses were underestimated in all cases like previous works [1, 2]. These results show that both TPS have limitations in low dose calculation beyond the field edge, due to complexity in scatter radiation models, specially with presence of block field scatter elements in IMRT with compensator filters.

Although in radiotherapy the low doses are presented in terms of differences related to prescribed dose, for TPS MIRS relative difference of -2.7% at 6.5 cm from the field edge implies an absolute difference of -55.7%. TPS Eclipse improves dose calculation. It is observed that it models better scatter components introduced by the block element with relative difference of -1.9% to 6.5 cm from the field edge and absolute difference of -39.4%.

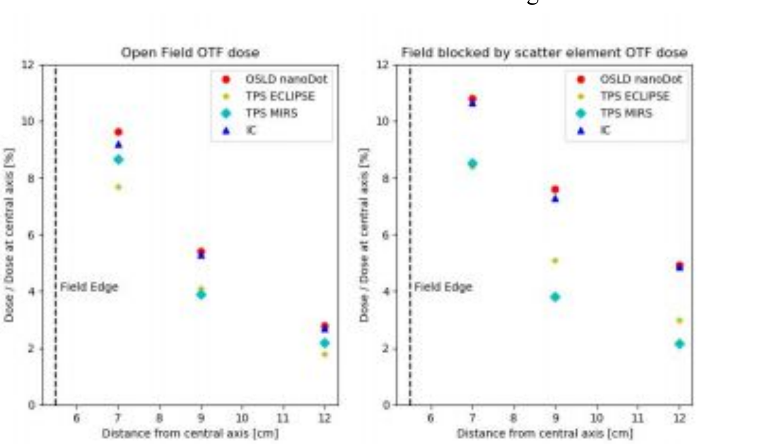

FIGURE 2. OTF dose normalized to central beam axis dose. Dose values correspond to OSLD, IC and TPS measurements for open field and field blocked by a scatter element.

Table 1 shows absolute and relative differences obtained for CIRS phantom and intracavitary IVD tests. The OTF dose calculated by TPS MIRS shows underestimation of -34.5% in terms of absolute difference for a point located 4 cm outside the field edge with respect to the IC measured dose. The OSLD measured dose shows good agreement in absolute terms with respect to IC. The OSLD results obtained in phantom with differences less than 3.0% turn this detector into a reliable alternative in the measurement of low doses at OARs OTF in IMRT treatments.

From intracavitary IVD results in Table I several characteristics stand out: i) TPS MIRS underestimates OTF dose of IMRT with compensator filters, in concordance with the characterization by experimental tests in phantoms. ii) Maximum discrepancy is 5.9% for relative difference, however in terms of absolute difference it can reach 87.7%. It was found that TPS underestimated dose for all cases. These observations should be taken into account from the radiological and radiobiological protection outlook associated with these dose levels.

TABLE 1. Relative and absolute differences obtained by OTF low dose regions in CIRS anthropomorphic phantom and IVD at OAR in IMRT with compensator filters using OSL nanoDot. IC values are taken as reference for CIRS test. [a] TPS MIRS values are taken as reference for intracavitary IVD test. [b]

	Relative difference [%]	Absolute difference [%]
CIRS test		
OSLD[a]	0.1	3.0
TPS MIRS[a]	-1.3	-34.5
in vivo test		
OSLD (minimum)[b]	0.8	12.5
OSLD (mean)[b]	1.5	42.0
OSLD (maximum)[b]	5.9	87.7

CONCLUSIONS

The OTF measurements in IMRT with compensator filters have shown that TPS MIRS underestimates the dose in terms of absolute difference up to 87.7%. These results suggest that research should continue in this field as it becomes increasingly important to study the radiobiological and radiological protection impact of the overdose on OARs located out-of-the-treatment-field, mainly in techniques such as IMRT, image guided radiotherapy (IGRT), volume modulated arc therapy (VMAT) and stereotactic body radiotherapy (SBRT) where there is an increase in radiation through image positioning systems and scatter radiation fields as reflected by monitor units [7, 8]. In previews works, Zaleskaa et al concluded that cells located outside the main field showed a trend towards a stronger biological response to irradiation (3 to 5% lower survival fraction at all dose points) than cells irradiated in the primary beam [8]. Low linear energy transfer radiation produces greater biological DNA damage than primary photon radiation, and that this damage occurs mainly through double strand-breaks [9]. Care must be taken to limit the treatment area in the acquisition of images for patient positioning, in those treatments that all day images are acquired, especially if they are megavoltage [10]. OSLD nanoDot has shown to be a reliable alternative for measuring low doses out-of-the-treatment-field due to its response following IC measured dose, without the need to introduce correction factors for spectral change as suggested by some authors [6].

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