UNIVERSITÀ
DEGLI STUDI DI TRIESTE

The Abdus Salam
International Centre
for Theoretical Physics

Master of Advanced Studies in Medical Physics

“Dosimetric Study of Fetal Dose during External Beam Radiotherapy using OSLD”

STUDENT:

EDITH NATALIA VILLEGAS GARCIA

SUPERVISORS:

DR. MARTA PAIUSCO

DR. MARCO FUSELLA

Trieste, Italy. January 25th, 2021.

Introduction

- ▶ Cancer during pregnancy is not common (incidence of 1 in a thousand patient), but radiotherapy might be one of the best treatment options, on its own or combined with surgery or chemotherapy.
- ▶ Generally, doses to the fetus should be kept below 10 cGy, and as low as possible. Above this dose threshold, severe intellectual disability, malformations, and other effects are possible. The risk for cancer induction has no threshold and increases with dose. [2]

Introduction

- ▶ Fetal dose is outside the treatment field.
 1. Treatment Planning Systems are not designed to be accurate outside the treatment field
 2. Measurements out-of-field are outside reference conditions
 3. Mean energy is lower out-of-field.
- ▶ Luminescent detectors are popular choices, as they are small and can be used for both in-vivo and phantom measurements. Optically Stimulated Luminescent Dosimeters can be used, but their energy dependence has to be taken into account.

Objective

- ▶ The purpose of this study is to calibrate an OSL dosimetric system to measure doses outside the treatment field and compare dose measurements with the calculations from the Acuros algorithm in the Varian Eclipse TPS. Treatment plans for a breast and brain were used for this comparison. Additional measurements were done with radiochromic film.

Optically Stimulated Luminescence Dosimetry

- ▶ They are Crystals Stimulated by Light during readout, similar to Thermoluminescent Dosimeters.
- ▶ Absorbed energy is stored in “traps” after irradiation.

[1] AAPM TG 191

OSLD Reader

- ▶ Main components are a strong light source and a photomultiplier tube.
- ▶ The bare crystal is stimulated with a light source.
- ▶ Light emitted during recombination can be measured with the photomultiplier tube.
- ▶ The intensity of the emitted light by the crystal correlates with the amount of radiation it has been exposed to previously.

(b) OSLD reader

[1] AAPM TG 191

Methods

OSLD Calibration (Reference Conditions)

- ▶ Irradiations with a 6 MV beam in a Varian TrueBeam linac.
- ▶ Field size: 10 cm x 10 cm, SSD = 100 cm, 10 cm depth in solid water. 100 MU irradiations.
- ▶ Calibrated farmer chamber used as reference detector.
- ▶ Additional PDD Measurement with OSLD.

$$N_{D,w} = \frac{D_0}{(M_{0,corr}) \cdot k_F \cdot k_L \cdot k_Q \cdot k_\theta}$$

Out-of-Field Calibration

- ▶ OSLDs placed in a PMMA grid in between solid water slabs.
- ▶ Grid with different
- ▶ Distance off-axis was 37 cm.
- ▶ Field size: 10 x 10 cm, 6 MV beam.
- ▶ Farmer Chamber as reference.

3DCRT Breast Plan

- ▶ A Phantom consisting of Rando Alderson Slices, solid water and a fake breast were scanned in the simulator CT.
- ▶ A 3DCRT plan was created in Eclipse, with 2 wedged fields and 2 smaller fields (field in field technique) to obtain a uniform dose distribution.
- ▶ Only 6 MV were used, with a total dose of 60 Gy in 4 fractions.

3DCRT Breast Plan Measurements

- ▶ The plan was irradiated on a TrueBeam linac (total plan dose).
- ▶ OSLD grids and EBT3 film were placed at depths of 5, 10 and 15 cm.
- ▶ Films and OSLDs were processed the next day.

Brain Astrocytoma Plans

- ▶ PTV copied from patient to the phantom CT (rigid registration).
- ▶ Two plans were made on Eclipse: one 3DCRT and one VMAT plan.
- ▶ The 3DCRT plan had two main fields with 45 degree wedges and a smaller field each. The VMAT plan used two full arcs.
- ▶ A total dose of 60 Gy in 4 fractions was given, with only 6 MV beams.

(a) 3DCRT plan

(b) VMAT plan

Brain Plan Measurements

- ▶ The total plan dose was irradiated for both plans, on a TrueBeam linac.
- ▶ OSLD grids and EBT3 film pieces were placed at 5, 10 and 15 cm.
- ▶ Rando Alderson slices were replaced with solid water slices.

Results

In-Field Measurements

- ▶ The result is a calibration factor of **0.00211 cGy/counts** in reference conditions, for high doses read with the weak beam, or a ratio of 473 counts/cGy, with relative uncertainty of 2.82%.
- ▶ Depth Dose Curve agreed except in the surface.

Out of Field Calibration

Table 1. OSLD Readings

nanoDot	Mean	σ	CV (%)
1	30334	415	1,37
2	28591	295	1,03
3	30061	283	0,94
4	30671	343	1,12
Mean	29914,25	334	1,11
σ	916,77		
CV (%)	3,06		

The was of 3460 counts/cGy, or a calibration coefficient of 0.000289 cGy/count, with a relative uncertainty of 3.53%.

The uncertainty is:

$$u_{\bar{r}} = \sqrt{u_{zero}^2 + u_{readings}^2 + u_{OSLDs}^2}$$

And:

$$\frac{u_{CF}}{CF} = \frac{u_{\bar{r}}}{\bar{r}}$$

Verification in Different Conditions

= 5 cm

= 15 cm

Breast Plan Measurements

- ▶ Verification Measurement were done with a 10 cm x 10 cm field (30 cm off-axis).
- ▶ There was good agreement with the farmer and OSLD chamber measurements, which validated the calibration factor.

Detector	Dose (cGy)
Farmer Chamber	13,71
nanoDot	13,91
Difference (%)	1,46

TPS vs Measured Dose (Breast Plan)

- ▶ The TPS significantly underestimated the dose in all cases. The dose differed by 40% at a depth of 5 cm, 48% at a depth of 10 cm and 67% at a depth of 15 cm, taking the OSLD measurement was the reference dose, and at a distance of 20 cm from the isocenter.

TPS vs Measured Dose (Brain Plans)

- For the 3DCRT, the DTA (Distance To Agreement) was 25 cm for the nearest measurement point and TPS calculation. The dose underestimation was a lot more significant in this case than in the breast plan. For the VMAT, the DTA for the nearest measurement point (32 cm from the isocenter) to the TPS calculation was 19 cm

Breast Fetal Doses

Treatment Site	Target Dose (Gy)	Fetal Dose (cGy)	Notes
	50	1.39	35 cm from the isocenter, at a depth of 9 cm. First trimester. [18]
		2.37	30 cm from the isocenter, at a depth of 9 cm. [18]
	50	4.4	24,5 cm from edge of the field, average dose. Monte Carlo simulation of two tangential 10.5 cm × 19.0 cm fields without wedges. First trimester. [19]
		6.4	14,5 cm from edge of the field. Second trimester. [19]
+ chest wall and lower axilla	46	3.9	29 cm between fundus and lower limit of radiation field. Two opposed tangential 7 cm x 15 cm fields without wedges. First trimester. [20]

For the depth of 10 cm, the resulting dose was 2.5 cGy for the breast plan at a distance of 30 cm from the isocenter.

Brain Fetal Doses

Treatment Site	Target Dose (Gy)	Fetal Dose (cGy)	Notes
	65	1.7	71.5 cm from isocenter. Two lateral opposed fields, 6 MV. Field size: 8 cm x 8 cm. First trimester. [21]
		2.17	51.5 cm from isocenter (upper dose). Second trimester. [21]
		2.83	59 cm from isocenter (upper dose). Third trimester. [21]
Single metastasis	30	0.3	70 cm from isocenter, 16 cm depth. Whole brain irradiation, shielding and special positioning used to reduce fetal dose. Third trimester. [22]
Astrocytoma	54	2.2	45 cm from the tumour volume at surface. Three coplanar fields used. Third trimester. [23]
Glioblastoma	60	2.4	40 cm from isocenter, 2 cm deep under a bolus. IMRT (6 MV), unshielded dose. Third trimester. [24]
		1.6	Shielded dose. [24]
Glioma	14	4.4	56 cm from isocenter at a depth of 8.5 cm. Radiosurgery with Cyberknife. Third trimester. [25]

For the brain astrocytoma plans, the doses were 0.8 cGy for the conformal plan and 1.1 for the VMAT plan, at a distance of 52 cm from the isocenter.

Conclusions

- ▶ The Acuros calculation algorithm in Eclipse greatly underestimates the out of field dose and can be used only for a rough estimation in positions not so far to the field edges. Landauer nanoDot dosimeters can be used with a phantom for these measurements. OSLDs should be calibrated out-of-field in similar conditions.
- ▶ Out-of-field doses for a breast plan and a 3DCRT and VMAT brain plans: For the depth of 10 cm, the resulting dose was 2.5 cGy for the breast plan at a distance of 30 cm from the isocenter. For the brain astrocytoma plans, the doses were 0.8 cGy for the conformal plan and 1.1 for the VMAT plan, at a distance of 52 cm from the isocenter. These values are below the limits and comparable to previous results.

References

- [1] Kry, Stephen F., et al. "AAPM TG 191: Clinical use of luminescent dosimeters: TLDs and OSLDs." *Medical physics* 47.2 (2020): e19-e51.
- [2] Stovall, Marilyn, et al. "Fetal dose from radiotherapy with photon beams: report of AAPM Radiation Therapy Committee Task Group No. 36." *Medical physics* 22.1 (1995): 63-82.
- [3] Kry, Stephen F., et al. "AAPM TG 158: measurement and calculation of doses outside the treated volume from external-beam radiation therapy." *Medical physics* 44.10 (2017): e391-e429.
- [4] Zhuang, Audrey H., and Arthur J. Olch. "Validation of OSLD and a treatment planning system for surface dose determination in IMRT treatments." *Medical physics* 41.8Part1 (2014): 081720.
- [5] Scarboro, S. B., and Stephen F. Kry. "Characterisation of energy response of Al₂O₃: C optically stimulated luminescent dosimeters (OSLDs) using cavity theory." *Radiation protection dosimetry* 153.1 (2013): 23-31.
- [6] Chofor, Ndimofor, et al. "Low-energy photons in high-energy photon fields—Monte Carlo generated spectra and a new descriptive parameter." *Zeitschrift für Medizinische Physik* 21.3 (2011): 183-197.
- [7] Lehmann, Joerg, et al. "Angular dependence of the response of the nanoDot OSLD system for measurements at depth in clinical megavoltage beams." *Medical physics* 41.6Part1 (2014): 061712.
- [8] Scarboro, Sarah B., et al. "Characterization of the nanoDot OSLD dosimeter in CT." *Medical physics* 42.4 (2015): 1797-1807.
- [9] Brown, Thomas AD, et al. "Dose-response curve of EBT, EBT2, and EBT3 radiochromic films to synchrotron-produced monochromatic x-ray beams." *Medical physics* 39.12 (2012): 7412-7417.
- [10] Sorriaux, Jefferson, et al. "Evaluation of Gafchromic® EBT3 films characteristics in therapy photon, electron and proton beams." *Physica Medica* 29.6 (2013): 599-606.
- [11] Devic, Slobodan, Nada Tomic, and David Lewis. "Reference radiochromic film dosimetry: review of technical aspects." *Physica Medica* 32.4 (2016): 541-556.
- [12] Scarboro, Sarah B., et al. "Energy response of optically stimulated luminescent dosimeters for non-reference measurement locations in a 6 MV photon beam." *Physics in Medicine & Biology* 57.9 (2012): 2505.
- [13] Chofor, Ndimofor, Dietrich Harder, and Björn Poppe. "Non-reference condition correction factor k_{NR} of typical radiation detectors applied for the dosimetry of high-energy photon fields in radiotherapy." *Zeitschrift für Medizinische Physik* 22.3 (2012): 181-196.

References

- [14] Chofor, Ndimofor, Dietrich Harder, and Björn Poppe. "Supplementary values of the dosimetric parameters kNR and Em for various types of detectors in 6 and 15 MV photon fields." *Zeitschrift für Medizinische Physik* 24.1 (2014): 27-37.
- [15] Kerns, James R., et al. "Angular dependence of the nanoDot OSL dosimeter." *Medical physics* 38.7 (2011): 3955-3962.
- [16] Jursinic, Paul A. "Characterization of optically stimulated luminescent dosimeters, OSLDs, for clinical dosimetric measurements." *Medical physics* 34.12 (2007): 4594-4604.
- [17] Yukihiro, E. G., et al. "Evaluation of optically stimulated luminescence (OSL) dosimeters for passive dosimetry of high-energy photon and electron beams in radiotherapy." *Medical physics* 35.1 (2008): 260-269.
- [18] Ögretici, Akin, et al. "Investigation of conformal and intensity-modulated radiation therapy techniques to determine the absorbed fetal dose in pregnant patients with breast cancer." *Medical Dosimetry* 41.2 (2016): 95-99.
- [19] Mazonakis, Michalis, Antonis Tzedakis, and John Damilakis. "Monte Carlo simulation of radiotherapy for breast cancer in pregnant patients: how to reduce the radiation dose and risks to fetus?." *Radiation protection dosimetry* 175.1 (2017): 10-16.
- [20] Antypas, Christos, et al. "Fetal dose evaluation during breast cancer radiotherapy." *International Journal of Radiation Oncology* Biology* Physics* 40.4 (1998): 995-999.
- [21] Mazonakis, M., et al. "Brain radiotherapy during pregnancy: an analysis of conceptus dose using anthropomorphic phantoms." *The British Journal of Radiology* 72.855 (1999): 274-278.
- [22] Magne, N., et al. "Radiotherapy for a solitary brain metastasis during pregnancy: a method for reducing fetal dose." *The British journal of radiology* 74.883 (2001): 638-641.
- [23] Haba, Y., et al. "Radiotherapy for glioma during pregnancy: fetal dose estimates, risk assessment and clinical management." *Clinical Oncology* 16.3 (2004): 210-214.
- [24] Horowitz, David P., et al. "Fetal radiation monitoring and dose minimization during intensity modulated radiation therapy for glioblastoma in pregnancy." *Journal of Neuro-oncology* 120.2 (2014): 405-409.
- [25] Pantelis, Evaggelos, et al. "Radiation dose to the fetus during CyberKnife radiosurgery for a brain tumor in pregnancy." *Physica Medica* 32.1 (2016): 237-241.
- [26] Mazzola, Rosario, et al. "Modern radiotherapy in cancer treatment during pregnancy." *Critical Reviews in Oncology/Hematology* 136 (2019): 13-19.