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Original Article

Silastic Thickness Optimization in Uveal Melanoma Brachytherapy by Monte Carlo Method

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Abstract

Introduction
In order to treat uveal Melanoma , first, radioactive seeds are laid on a silicone- made substance which is called Silastic after that they are inserted in the plaque, and finally, this plaque containing silicone-made substance is stitched to the sclera surface. The dose gradient within the tumor and healthy tissues can be varied due to changing the Silastic thickness between sclera surface and radioactive seeds. In turn, this leads to difference in the amount of absorbed dose of tumor and healthy tissues. Present study is to investigate the optimum Silastic thickness in uveal Melanoma brachytherapy.
Materials and Methods
To measure changes of depth dose of the plaque in a sphere with a radius of 12 mm, MCNP4C code was applied. Exact specifications of a 20-mm Collaborative Ocular Melanoma Study (COMS) plaque, Silastic and three I-125 seed sources, 6711 model were integrated in simulation. Dose calculations were performed using F6 tally in spheres with a radius of 0.2 mm.
Results
By measuring the changes of dose rate of plaque in distances of 0.2 to 18 mm from the sclera surface and having the prescribed dose for the absolute treatment of eye melanoma, final absorbed doses by tumor and healthy tissues for each different Silastic thicknesses of 0, 0.5, 1, 1.5, and 2 were calculated.
Conclusion
Considering the results and sclera tolerance, it was concluded that the thickness of Silastic must not exceed 0.5 mm, because increasing the Silastic thickness from this area, increases absorbed dose by healthy tissues and also the treatment time.

Keywords: Uveal Melanoma; I-125 Source; Monte Carlo; Silastic.

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1. Introduction

Uveal melanoma is a rare but life-threatening form of intraocular tumors with mean incidence of less than one new case per 100,000 people each year. It is the most common primary intraocular malignancy (about 75% of all primary malignant tumors) [1, 2]. Plaque therapy is an available option at any center associated with a well-staffed radiotherapy facility. Radiation sources for plaques include Rn-222, Au-198, Co-60, Ir-192, Pd-103, I-125, and Ru-106 seeds [3]. Currently, I-125 is the most commonly used and well-documented radioisotope for this purpose in the literature [3]. I-125 decays through electron capture to Te-125 and emits photons as presented in Table 1 in [3].

The half-value layer of I-125 photons is 20 mm in tissue. The typical size for a tumor eligible for a treatment with I-125 is between 7 to 15 mm in height between the base and apex [4]. The tumor size and the half-value layer are close to each other, making I-125 a suitable radionuclide for treating ocular tumors [5].

The applicator for I-125 treatments is often called plaques. The plaques are available in different sizes and designs, for example cut-outs to spare the iris or optic nerve [4].

The radioactive material in ophthalmic plaques is distributed uniformly (Ru-106) and non-uniformly (I-125). In the non-uniform distribution method, radioactive material as a seed is placed on the plaque. By selecting different activities for the seeds, different number of seeds and different arrangement of the seeds on the plaque and the dose distribution can be optimized according to the size and shape of the tumor.

The Collaborative Ocular Melanoma Study (COMS) developed a standardized set of eye plaques that consists of a 0.5 mm thick bowl-like gold alloy backing with a cylindrical collimating lip. A Silastic (silicone polymer) seed carrier into which I-125 seeds are loaded has been designed to fit within the backing. The carrier provides a standardized seed pattern and functions to offset the seeds by 1.0 mm from the concave (front) surface of the carrier. These Silastic carriers have been found to be difficult to load and preclude flash sterilization, and also be a source of dosimetric uncertainty because the effective atomic number of Silastic is significantly higher than that of water. The main dosimetric effect of the Silastic carrier is a dose-reduction (compared with homogeneous water) of approximately 10-15% for I-125 radiation [4].

Briefly, Silastic consists of a 1-mm thick bowl-like Silicon alloy (40% Silicon, 25% carbon, 6% hydrogen, 29% oxygen, and 0.005% palladium) in which I-125 seeds are loaded [6]. A customized configuration of typically 4 to 20 radioactive seeds is fixed in a gold plaque, and the plaque is sutured to the scleral surface corresponding to the basis of the intraocular tumor, allowing for a localized radiation dose delivery to the tumor. A lot of works have been done in the field of eye plaque dosimetry, including Knutsen and colleagues study [7]. Relative dose distributions in a water phantom, including central axis depth dose and off-axis dose profiles for the COMS 20-mm plaque were measured with a diode detector. The plaque was arranged with three realistic I-125 seed (Amersham model 6711) configurations. Measured dose distributions were compared with the corresponding dose profiles calculated with the Treatment Planning System [7].

Silastic acts as a separator of the seeds from the concave (front) surface of the carrier by a distance of 1.0 mm [7]. Therefore, the seed distance from the tumor surface depends on the Silastic thickness. Due to the high dose gradient near the source, the change of the Silastic thickness can affect the dose received by the tumor and the healthy tissue as well as the treatment time. As a result, the effect of different Silastic thicknesses on the absorbed dose in healthy tissues surrounding the tumor and the treatment time was evaluated. Finally, an optimum thickness for Silastic was suggested for the treatment of ocular melanoma. Because of the high dose gradient near the brachytherapy sources, dependence of the absorbed dose on the location of dosimeters and the inhomogeneous dose

distribution around the plaque, the evaluation of this effect using experimental dosimetry does not provide enough accuracy [8].. Herein, this effect was evaluated using the Monte Carlo method which provides a high accuracy in the high dose gradient regions.

2. Materials and Methods

In this article, the source, the plaque, the eyeball, and the Silastic were simulated using MCNP4C code and the depth-dose distribution along the central axis of the plaque was calculated as a function of the Silastic thickness.

2.1. Characteristic of I-125

I-125 with the half-life of 59.46 days decays to Te-125 through the electron capture process [4]. Photon disintegration of this radionuclide is shown in Table 1. The iodine seeds were simulated as assemblies in the titanium rods with a diameter of 0.8 mm and length of 4.5 mm. Each titanium rod contained a silver core with a length of 3 mm which was coated with Palladium and I-125 radionuclides. The irradiated low energy beta-particles were neglected in the simulation process because of the self-absorption in the internal structure of the seeds. In this research, three 7611 Amersham model iodine seeds were utilized. Figure 1 demonstrates geometric properties of the utilized source [9].

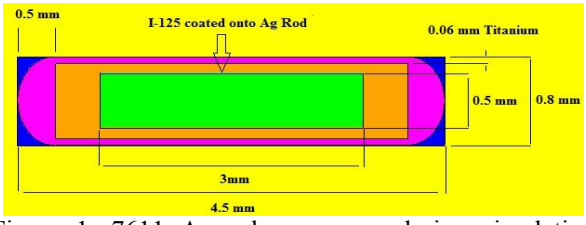

Figure 1. 7611 Amersham source design simulation model [۹].

2.2 Properties of the plaque

In this research, a 20-mm COMS model plaque contained three seed sources of I-125 (7611 model) was utilized. The schematic of the simulated plaque and the arrangement of the radiation seeds are shown in Figure 2. The properties of constituents of the simulated plaque are summarized in Table 2.

Table 1. The energy spectrum and branch ratio of each photon per decay I -125.

Photon Energy (keV)	Branching Ratio
27.2	0.405
27.47	0.756
30.98	0.202
31.88	0.043
35.45	0.067

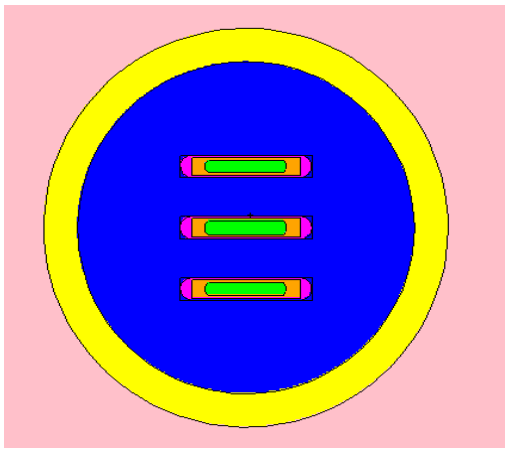

Figure 2. The design of the simulated plaque and arrangement of radioactive seeds.

Table 2. Material characteristics of the simulated plaque.

Materials	Composition Percent
Au	77
Ag	14
Cu	0.08
Pd	0.01

2.3. The Phantom and Dosimetry

In order to calculate the dose received by the eyeball along its central axis, the plaque should be placed on the surface of a 12-mm radius spherical water phantom. Figure 3 shows the schematic of the simulated geometry. The dose distribution along the central axis of the plaque was calculated using the F6: p Tally within the 0.2 mm radius

micro-spheres with a surface to surface distance of 0.1 mm (Figure 3).

In order to evaluate the influence of Silastic thickness on the dose distribution, the discussed procedure was repeated for 0, 0.5, 1, 1.5, and 2 mm thicknesses of Silastic. It is worth to note that the standard method to calculate the dose distribution in MCNP4C code uses *F8 tally, but since the radiation sources emit low energy particles and the micro spheres were placed outside the buildup region, it can be concluded that the electronic equilibrium condition are satisfied. Therefore, the dose distribution could be calculated using F6 instead of *F8 tally. We must mention that the particle number and the relative errors in our calculations are 10e7 and less than 2%, respectively . It has the advantage of significant reduction in the code run time. Furthermore, the difference between the results obtained by the two tallies differ less than 2% within the near micro-spheres.

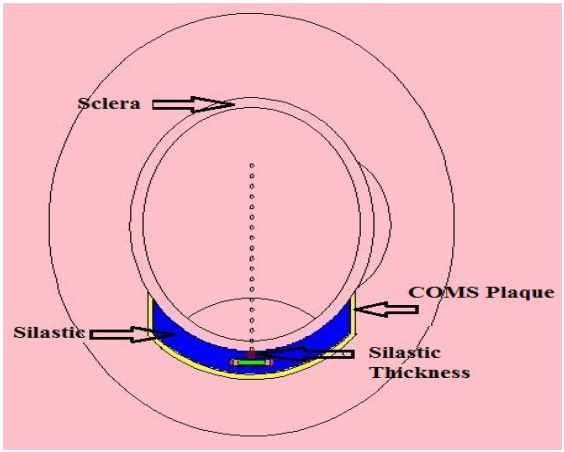

Figure 3. The design of simulated geometry in this study.

3. Results

The clinical protocol for the treatment of ocular melanoma is defined based on that 85 Gy delivered to the tumor apex (In this study, a distance of 5 mm from the surface Sclera) [10].

Thus, depending on the dose absorbed by the reference point and having the absorbed dose at the point of dose absorption, rates and treatment time in different parts of the tumor and the healthy tissue behind the tumor were calculated for different Silastic thickness. The results are shown in Tables 3 and 4.

Table 3 shows the absorbed dose along the central axis of the plate for different Silastic thicknesses. Table 4 shows the time required for the treatment for various thicknesses of Silastic.

Figures 1, 2, and 3 indicate the amount of absorbed dose along the central axis of the plaque, tumor, and normal tissue behind the tumor, respectively.

Finally, the simulation results for 1-mm Silastic thickness was validated by the Knutsen study [7]. The good agreement of our simulation results with the work of Knutsen et al. demonstrates the validity of this simulation (Figure 7 and 8).

Table 3. The absorbed dose along the central axis of the plaque for different Silastic thicknesses according to Gy.

Distance from Sclera (mm)	Silastic Thickness (mm)				
	0	0.5	1	1.5	2
0.2	1752.23	1063.31	792.13	650.44	552.84
0.5	1122.86	803.03	644.39	540.19	472.10
1	682.52	552.12	469.39	411.45	365.65
2	338.71	304.62	275.92	253.21	238.02
3	196.91	186.66	176.63	168.79	161.97
4	125.27	124.14	120.42	115.72	115.34
5	85	85	85	85	85
6	60.90	61.97	63.34	64.50	66.17
7	45.00	47.41	48.63	49.89	51.01
8	34.51	36.74	38.03	39.78	41.56
9	26.98	28.84	30.94	31.66	33.00
10	21.41	23.05	24.11	25.60	27.41
11	17.08	18.60	19.49	21.25	22.88
12	14.13	15.94	16.98	18.32	19.27
13	12.06	12.97	14.02	15.53	16.14
14	10.21	11.07	12.05	12.74	13.40
15	8.37	9.72	10.40	10.83	11.33
16	7.20	8.00	8.71	9.14	10.12
17	6.18	6.99	7.59	8.21	9.196
18	5.30	5.97	6.48	6.96	7.87

Table 4. The time required for definitive treatment for various thicknesses Silastic.

Silastic Thickness (mm)	0	0.5	1	1.5	2
Treatment Time (h)	1116.0	1419.62	1764.18	2169.8	2648.42

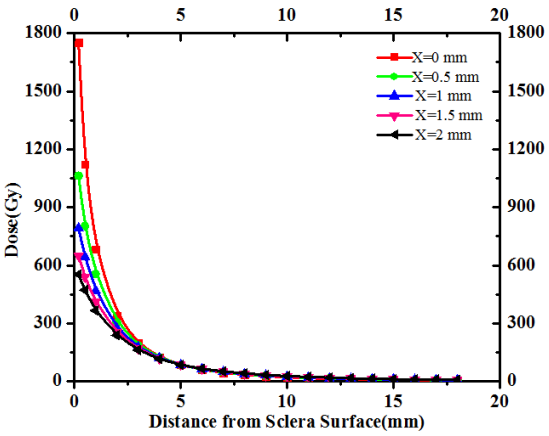

Figure 4 The absorbed dose along the central axis of the plaque.

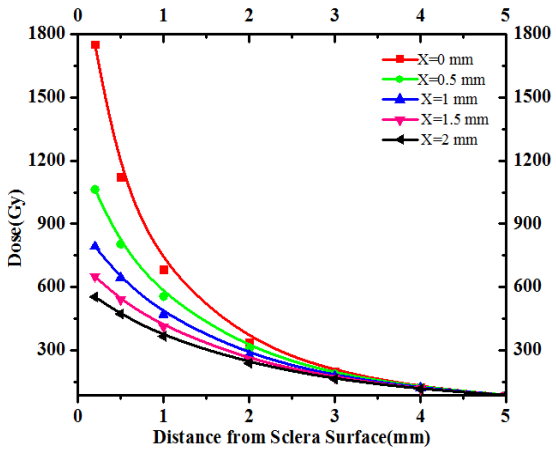

Figure 5.. The received dose to different depths of tumor for different thicknesses of Silastic.

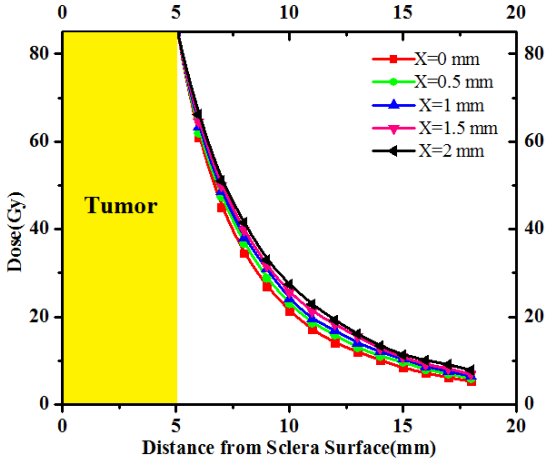

Figure 6. The received dose to different depths of normal tissue behind the tumor for various thicknesses of Silastic.

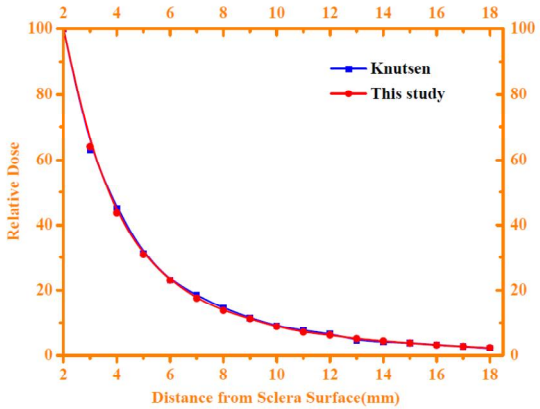

Figure 7. Comparison of percentage depth dose for this study with Knutsen experimental results.

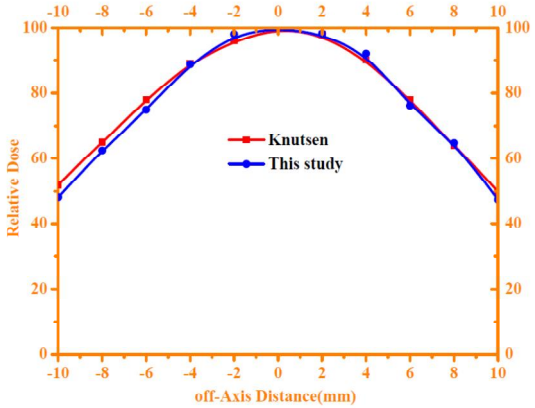

Figure 8. Plaque dose profiles at 10-mm depth of this study and Knutsen's experimental results.

4. Discussion

It was observed that the tumor dose remained within the low dose gradient region as the Silastic thickness increased (Figure 6) and the dose received by the normal tissue increased (3). In order to achieve a prescribed dose, an increase in the treatment time was required (Table 4). It resulted in an increased total absorbed dose which can exceed the tolerance dose of adjacent healthy tissues.

On the other hand, when the source was placed in contact with the surface of the tumor, the tumor received the maximum dose while the normal tissue behind the tumor received the minimum dose. However, the absorbed dose of the sclera in this case was 1752.23 Gy which in comparison with the tolerance dose of 1200 Gy for this organ is too high. Therefore, a Silastic thickness of more than 0.0 mm was required.

5. Conclusion

Based on the results, it can be concluded that decreasing the Silastic thickness leads to a shift in high dose gradient toward the tumor region and a decrease in the absorbed dose by the healthy tissues. Thus, less treatment time is required when the Silastic thickness decreases.

The absorbed dose in sclera is a function of the Silastic thickness and it should be adequately thick to limit the final received dose within the recommended criteria. Thus, the Silastic thickness should be compromised between the absorbed dose within the tumor, the healthy tissue, and the dose received by the sclera. The results of this study showed that the Silastic thickness between 0 and 0.5 mm creates the desired balance of the maximum dose to the tumor and the minimum (less than the tolerance) dose to the sclera. This study can provide an efficient and optimum solution in the treatment of the ocular tumors.

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