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Evaluation of Surface Dose for Intensity Modulated Radiotherapy of Head and Neck Cancer Using Thermoluminescent Dosimeters

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Keywords

Thermoluminescent Dosimeter
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Abstract

Accurate estimation of the surface dose in radiotherapy of patients with head and neck cancer is very important in terms of treatment. The aim of this study is to evaluate the surface dose for intensity-modulated radiotherapy (IMRT) of head and neck cancer using thermoluminescent dosimeters (TLDs). In addition, it is aimed to examine the surface dose estimates of the treatment planning system (TPS) for different grid sizes. Before the computed tomography (CT) images were taken for 15 head and neck cancer patients, 5 different points determined in the neck region were marked in a way that would not cause artifacts. IMRT plans are created for 1.5 and 2.5 mm grid sizes. Surface doses were obtained for TPS calculations and TLD measurements at 5 different points in the neck region. Surface doses obtained from TLD measurements and TPS calculations with different grid sizes were compared. All patients received 3-stage adaptive radiotherapy (ART) and the surface dose comparison was repeated for each plan. According to plan 0, the height of TLD measurements for the 1.5 and 2.5 mm grid size were 4.06% and 7.87%, respectively. In Plan 1, the difference between TPS and TLD doses was 4.00% and 8.15% for grid size 1.5mm and 2.5mm, respectively (p=0.00 and p=0.00). For dose measurements from Plan 2, the difference between TPS and TLD doses was 4.07% and 9.96% for grid size 1.5mm and 2.5mm, respectively (p=0.00 and p=0.00). Surface doses obtained in TLD measurements for all treatment plans were higher than in TPS dose calculations. Accurate estimation of the surface dose in head and neck cancer radiotherapy is very important for treatment. Surface doses calculated with TPS are usually lower than the prescribed dose. Therefore, during the evaluation of radiotherapy plans, it should be considered that TPS underestimates the surface dose. This ratio can be determined by dosimetric measurements. Thermoluminescent dosimeters are suitable equipment for this process.

Cite

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1. INTRODUCTION

The existence of developments in technology from the past to the present has led to great advances in the field of medicine. These technological developments have been an important reform in the treatment of cancer with radiation. With the technological developments, the treatment techniques used in radiotherapy have also developed. As a result of these developments, the intensity-modulated radiotherapy (IMRT) technique is widely used today. The desired dose distribution with the IMRT technique is defined in the treatment planning system (TPS) (McLaughlin et al., 2017; Wang et al., 2022). Radiotherapy planning in head and neck cancers is a very complex procedure due to the complex anatomical structure and the presence of many sensitive tissues adjacent to the target volume (Lo Nigro et al., 2017). Accurately knowing the surface dose in IMRT is important for estimating side effects during the evaluation of the treatment plan. Acute skin reactions can be prevented by accurately knowing the surface dose (Lee et al., 2012). During radiotherapy, skin reactions occur depending on the dose rate, technique used, surface dose and total dose (Wei et al., 2019). Radiation is absorbed

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in all tissues it comes into contact with. Therefore, accurate calculation of these tissue doses by TPS is very important. Grid size affects especially surface dose calculations of complex treatments such as IMRT. However, the calculation grid size is usually left at a default value to minimize the time it takes for the TPS to perform dose calculations. Although TPSs calculate very similar dose distributions to actual doses in critical organs and tumor volume, they fail at surface doses. However, skin dose toxicity has a major impact on a patient's ability to tolerate treatment well (Sarkar et al., 2020). Since the radiation dose given by the IMRT technique is not homogeneous, it is difficult to calculate the surface dose accurately by TPS (Tai et al., 2019). Therefore, actual surface doses should be verified by more reliable methods. For this purpose, in vivo measurement for accurate surface doses may be a solution. In vivo measurement methods are used in the evaluation of radiation in the body. Knowing the correct surface dose will help in estimating the skin reactions that may occur during the treatment process. Thermoluminescent dosimeters (TLD) are widely used today to accurately measure surface doses. The effective atomic number of TLDs is very close to that of human tissue. Therefore, it is widely used in surface entrance dose measurements in radiotherapy (Moghaddam et al., 2013).

The aim of this study is to evaluate the surface dose for intensity modulated radiotherapy of head and neck cancer using thermoluminescent dosimeters. In addition, it is aimed to examine the surface dose estimates of the treatment planning system for different grid sizes.

2. MATERIAL AND METHOD

Patient selection and Contouring

15 patients with head and neck cancer were included in this study and permission was obtained from the ethics committee of Selcuk University Faculty of Medicine with the decision numbered 2022/182. Since skin toxicity is generally seen around the neck of the patient in head and neck cancer patients, patients whose both necks were irradiated were selected. Other information about the patients is given in Table 1.

Table 1. *Patient characteristics*

Characteristics	Patients, n (%)
Sex	
Male	13 (86.7)
Female	2 (13.3)
Age, years	
Range	33-78
Median	57
KPS score	
100	2 (13.3)
90	7 (46.7)
80	6 (40.0)
BMI	
Range	21.1-38.8
Median	27
AJCC stage grouping	
I	1 (6.7)
II	5 (33.3)
III	8 (53.3)
IVA	1 (6.7)

KPS; Karnofsky Performance Score, BMI; Body Mass Index

Before the Computed tomography (CT) image of each patient was taken, 5 different points determined in the neck region were marked so as not to cause artifacts. CT scan of all patients was obtained with a slice thickness of 3 mm. All CT images were acquired with the Toshiba Aquilion S4 device. Plan0 was generated from initial CT images. Adaptive radiotherapy (ART) technique is the method that minimizes the dosimetric differences that may occur between the planned and applied treatment, taking into account the changes in the field where the radiotherapy is applied. During the treatment, CT was taken for control purposes. The target volume and critical organs were recontoured on the control CT. The patient's plan was made over the new CT. Plan1 was generated from the control CT obtained in the 14th fraction and Plan2 was generated from the control CT obtained in fraction 24. When the volume and doses were compared and a significant difference was found, the patient continued his treatment with the new adaptive plan. ART was applied to all 15 patients included in the study. Target volume and critical organs for all patients are contoured by a single radiation oncologist.

Treatment planning and analysis

Treatment plans were calculated with the AAA algorithm in the Eclipse 15.1 planning system. All plans were made in IMRT technique using 6 MV energy. For all treatment plans, 98% of target volumes were considered to cover 100% of the defined dose. Each IMRT plan was coplanar and had gantry angles of 0°, 52°, 104°, 156°, 204°, 256°, and 308°. A dose rate of 300 MU/min was used for all IMRT plans. 70 Gy in 33 fractions was planned for the primary target volume. Due to weight loss and decreased tumor volume in the patients included in the study, two adaptive radiotherapy was applied for each patient, except for the initial plan. IMRT plans with grid sizes of 1.5 and 2.5 mm were created using the AAA algorithm for each patient included in the study. TPS dose calculation results were obtained from 5 different points determined during CT for each IMRT plan. All patients received 3-phase adaptive radiotherapy due to weight loss and reduction of tumor volume. All patients received 3-stage ART. Accordingly, Plan0, plan1 and plan2 were applied between 0-14, 15-24 and 25-33 fractions, respectively.

In vivo surface dose measurements

TLDs are among the most preferred in vivo dosimeters for measuring dose exposure in radiotherapy due to their small size and high sensitivity. TLDs used in this study were lithium fluoride (LiF:Mg,Ti (TLD - 100)) doped with magnesium (Mg) and titanium (Ti). The effective atomic number of these dosimeters is 8.2 and are considered tissue equivalent dosimeters (Olaciregui-Ruiz et al., 2020). Surface dose measurements were made on the Varian DHX device in the Radiation Oncology Clinic of Selcuk University Medical Faculty Hospital. Necessary dosimetric measurements were made before the treatment. The difference between the measurements obtained and the acceptance tests of the linear accelerator was found to be within 1%. Each TLD was irradiated to receive 1Gy in a 10 cm x 10 cm field at SSD=100 cm and 1.5 cm from the surface. TLD-100 chips were calibrated and TLDs with dose reproducibility within ±1% were used for dose measurements. Annealing conditions of TLDs used in dose measurement; It was 1 hour at 100 °C and 2 hours at 100 °C. The Harshaw 3500 TLD reader, TLD furnace and aluminum tray separated by special partitions are shown in Figure 1, Figure 2 and Figure 3, respectively. TLDs were placed at 5 different marked points in the neck region in the 1st fraction for in vivo dose measurement. 5 different TLD locations on the patient's neck for TPS calculation and in vivo dose measurement are shown in the Figure 4. Three TLDs were placed in each region to minimize the deviation in the measured dose value. The dose value was calculated by averaging the dose value obtained from the three TLDs. TLDs were placed on the patient's skin before the treatment and removed at the end of the treatment. Afterwards, the TLDs were read and the surface dose was calculated. These dose measurements were repeated for each patient as adaptive radiotherapy was administered.

Statistical analysis

For statistical analysis and calculations in the study, Paired Sample t-test was used in the Statistical Package for Social Sciences (SPSS 25.1) program. In statistical decisions, $p<0.01$ was accepted as an indicator of significant difference.

Figure 1. *Harshaw 3500 TLD reader*

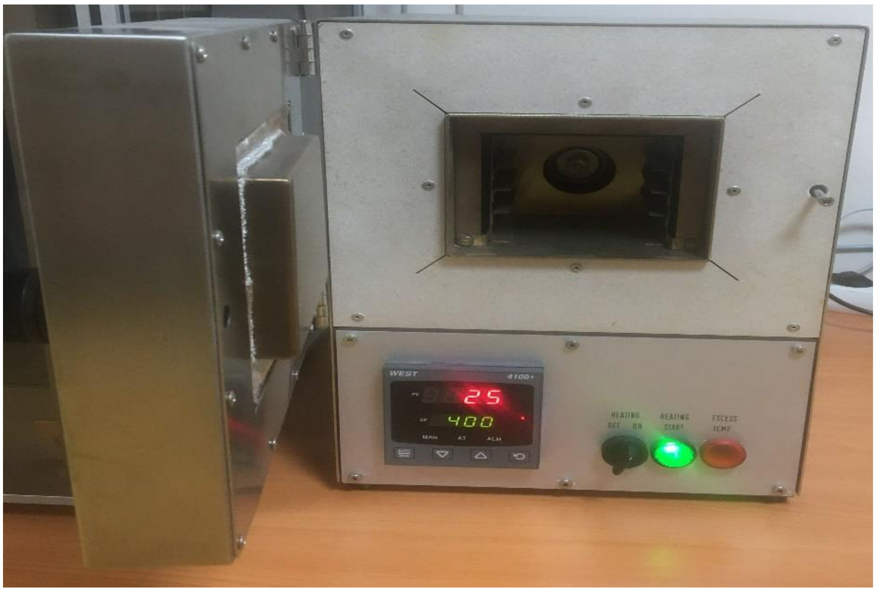

Figure 2. *TLD furnace*

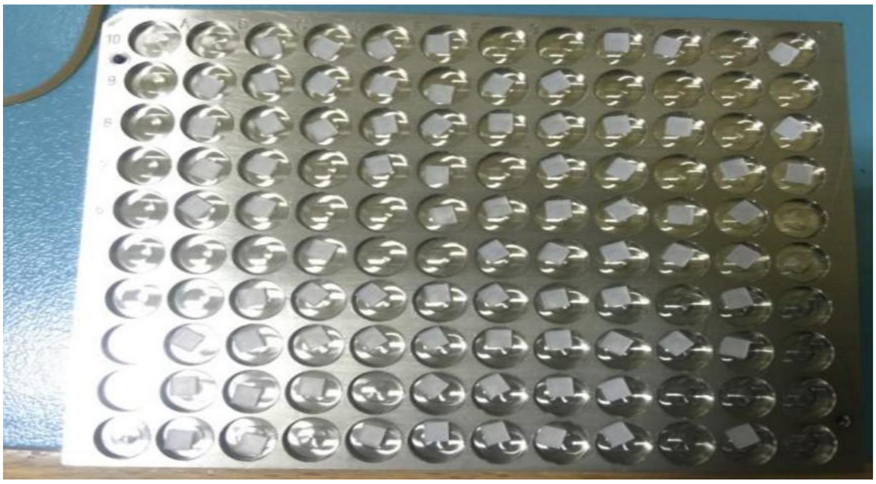

Figure 3. *Aluminum tray*

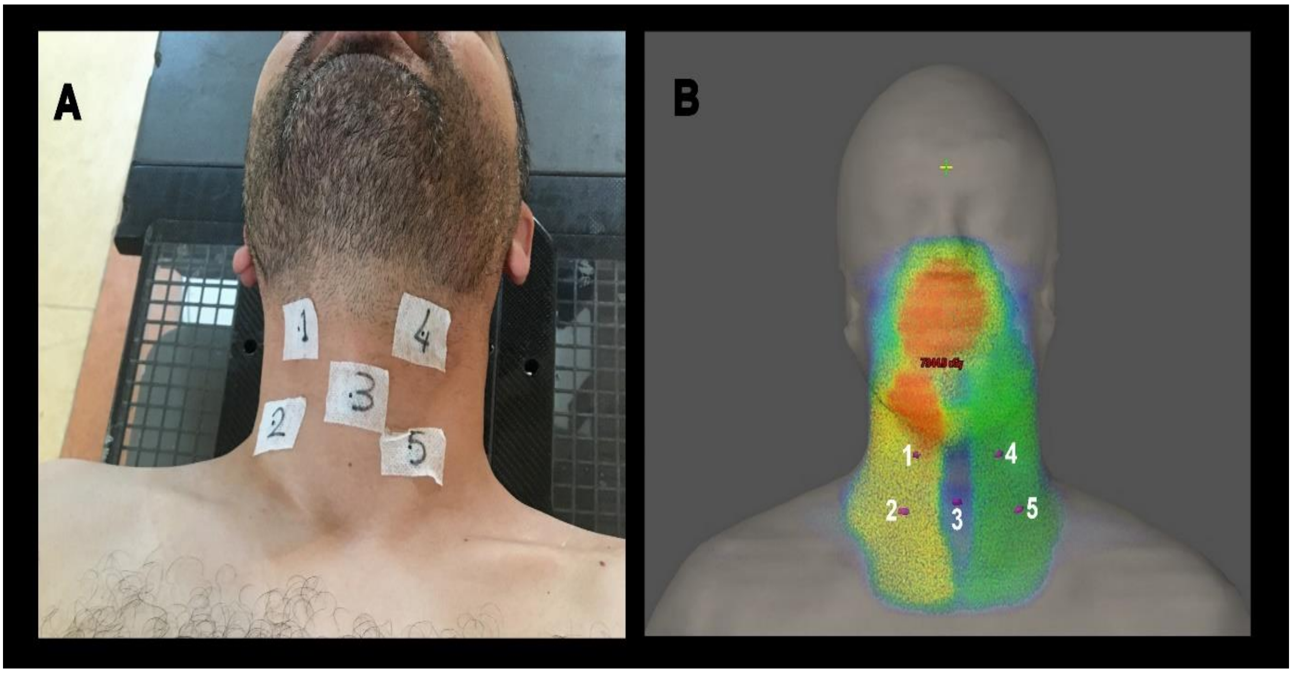

Figure 4. *5 different TLD locations on the patient's neck for TPS calculation and in vivo dose measurement,*
A) *Placement of TLDs at 5 different points on the neck before treatment,*
B) *Dose distribution for 5 different points determined in TPS calculation*

3. RESULTS AND DISCUSSION

5 different TLD placement plans on the neck of each patient are shown in Figure 1.The results of Eclipse TPS calculations for surface dose at different grid sizes in the IMRT technique and TLD measurements are shown in Table 2. Surface doses obtained in TLD measurements for all treatment plans were higher than in TPS dose calculations. The mean surface dose calculated for grid size 1.5 mm and 2.5 mm for Plan 0 was 160.94 cGy and 155.25 cGy, respectively. However, the mean surface dose with TLD was measured as 167.48 cGy. Accordingly, the height of TLD measurements was 4.06% and 7.87% for grid size 1.5 mm and 2.5 mm, respectively. The average surface dose calculated for the grid size 1.5 mm and 2.5 mm for Plan 1 was 162.91 and 156.97, respectively. The mean surface dose of the same plan with TLD was measured as 169.77 cGy. Accordingly, the difference for grid size 1.5mm and 2.5mm was 4.00% and 8.15%, respectively (p=0.00 and p=0.00). For the mean of Plan 2 administered to patients in the 25 and 33 fraction range, the mean surface dose with TLD was measured as 170.47 cGy. For the grid size of this IMRT plan 1.5 mm and 2.5 mm, the difference was 4.07% and 7.96%, respectively (p=0.00 and p=0.00). The highest difference between TLD measurements and TPS calculations for 5 different points marked in the neck region was the 3rd point. The difference between TLD measurements and TPS calculations in this region was 8.28% and 13.61% for grid size 1.5 mm and 2.5 mm, respectively. The comparison of TPS calculations for surface dose and statistical significance for TLD measurements in the IMRT technique is shown in Table 3.

Radiation therapy for head and neck cancer is generally at a daily dose of 200-250 cGy and a total of 6000-7000 cGy with 30-33 treatment sessions over 6 weeks. Due to various factors, patients with head and neck cancer may undergo significant anatomical changes during radiation therapy. The reasons for these changes may be due to many factors. These factors are; reduction in tumor and nodal volumes, weight loss, changes in muscle mass and fat distribution. It is of great importance to apply the determined dose correctly in order to increase regional control and reduce complications in the patient during irradiation treatment of head and neck cancers. Surface dose measurement in the head and neck region is difficult. Accurate knowledge of the surface dose in the neck region helps clinical decisions. Accurate estimation of neck surface dose is important to minimize acute skin reactions and toxicities. In the study, the mean daily dose calculated by TPS at 135 different points for a 1.5 mm grid size was 162.55 cGy, and the mean dose measured by TLD was 169.24. In addition, the mean difference between TPS calculations and TLD measurements was 4.11%. For all points on the skin surface, the doses measured by TLDs were higher than the doses calculated by TPS.

***Table 2.** Results of TPS calculations and TLD measurements for surface doses*

Plans	Location	TLD Mean±SD (cGy)	TPS Mean ± SD (cGy) Grid size (1.5mm)	Deviation (%)	Grid size (2.5mm)	Deviation (%)
0	1	175.15±15.88	168.02±17.16	-4.07	161.33±18.38	-7.89
0	2	175.54±13.54	169.02±11.02	-3.71	164.74±11.67	-6.15
0	3	163.27±26.91	149.78±29.66	-8.26	141.97±29.53	-13.04
0	4	162.45±17.63	160.29±13.07	-1,32	153.59±12.89	-5.45
0	5	160.99±14.65	157.59±14.83	-2.11	154.65±16.06	-3.93
1	1	175.60±14.81	170.05±12.73	-3.16	165.42±12.38	-5.79
1	2	175.96±14.54	170.79±12.60	-2.93	165.43±10.33	-5.98
1	3	165.93±24.91	152.19±27.42	-8.28	143.34±29.06	-13.61
1	4	167.80±12.58	161.86±12.47	-3.53	155.46±14.58	-7.35
1	5	163.55±15.24	159.65±13.90	-2.38	155.22±14.81	-5.09
2	1	176.93±15.85	171.91±14.64	-2.83	166.64±15.21	-5.81
2	2	178.15±15.49	171.53±15.50	-3.71	166.05±13.52	-6.79
2	3	163.71±24.09	151.43±24.27	-7.50	141.44±26.77	-13,6
2	4	168.04±14.84	162.69 ±15.09	-3.18	158.97±15.35	-5.39
2	5	165.55±15.45	161.38±14.75	-2.51	156.40±15.09	-5.52

***Table 3.** Comparison of statistical significance of surface doses for TPS calculations and TLD measurements*

Location	TLD vs TPS(Grid size;1,5mm)			TLD vs TPS(Grid size;2,5mm)		
	Plan 0	Plan 1	Plan 2	Plan 0	Plan 1	Plan 2
1	**0.002***	**0.000***	**0.000***	**0.000***	**0.000***	**0.000***
2	**0.000***	**0.001***	**0.000***	**0.000***	**0.000***	**0.000***
3	**0.000***	**0.000***	**0.000***	**0.000***	**0.000***	**0.000***
4	0.510	**0.000***	**0.000***	**0.000***	**0.000***	**0.000***
5	**0.004***	**0.001***	**0.000***	**0.000***	**0.000***	**0.000***

$p<0.01$

Price et al. (2014) investigated the TPS skin dose for different grid sizes in the IMRT treatment of head and neck cancer. According to this study, they found 21% and 9.5% difference between TPS and TLD measurements for 5 and 3 mm grid sizes, respectively. The research of Price et al. (2014) was found in parallel with our current study. Accordingly, 8.00% and 4.11% differences were found between TPS calculations and TLD measurements for 2.5 and 1.5 mm grid sizes, respectively.

Akbas et al. (2018) investigated the surface dose accuracy of TPS on a random phantom using radiochromic film for the treatment of laryngeal cancer with IMRT technique. They found that the surface doses calculated by TPS were lower than the radiochromic film measurements. In our study, the mean difference for TPS calculations and TLD measurements for IMRT plans was 8.00%.

Akino et al. (2013) compared the surface doses measured using EBT2 film in IMRT and field-in-field (FiF) treatment techniques for different grid sizes. He reported that the AAA algorithm failed to calculate the surface dose according to in-vivo measurements. They also suggested using the smaller computational grid size to accurately visualize the TPS dose. Our current research yielded similar results to the study of Akino et al. (2013). Accordingly, with the reduction of the grid size from 2.5mm to 1.5mm, the difference between TPS calculation and TLD measurements decreased from 8.00% to 4.11%, respectively.

Gopalakrishnan et al. (2021) measured in vivo surface doses uptake by the left breast and contralateral breast (CB). They compared the measured surface doses using OSLD with TPS calculations for five different treatment techniques. They found a 6.91% difference in surface dose between the TPS calculation and OSLD measurements for the IMRT technique. In our study, it was found that the surface dose calculated by TPS was lower than TLD measurements. This difference was 4.11% and 8% for grid size 1.5 and 2.5 mm, respectively.

4. CONCLUSION

Patients with head and neck cancer may undergo significant anatomical changes during radiation therapy for various reasons, and side effects for the skin are expected during the long treatment period. Therefore, accurate estimation of the dose on the skin surface of the patient is very important in terms of treatment. In our study, the surface doses calculated by Eclipse TPS are generally lower than the prescribed dose. Therefore, during the evaluation of radiotherapy plans, it should be considered that TPS underestimates the surface dose. This ratio can be determined by dosimetric measurements. It is very important to take in vivo dose measurements to minimize side effects in the treatment process. Thermoluminescent dosimeters are suitable equipments for this process. We recommend further use of in vivo dose measurements with TLD.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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