Skin Dosimetry with EBT3 Radiochromic Film in Radiotherapy of Parotid Cancer

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ABSTRACT

Background: Skin is a sensitive organ and should be spared in radiotherapy and irradiation of skin in radiotherapy can cause to acute and late skin effects such as erythema, desquamation, epilation, color change, or even necrosis.

Objective: The aim of the present study is to do skin dosimetry in radiotherapy of parotid cancer using Gafchromic EBT3 radiochromic film. EBT3 radiochromic films were calibrated in 0.2-5 Gy dose range.

Material and Methods: This is an experimental study in the field of radiotherapy physics. Treatment planning was performed on a RANDO phantom for treatment of parotid cancer by a clinical oncologist. Based on the treatment planning, the skin dose at various points in the overlapping region of right anterior-oblique and right posterior-oblique fields were measured using EBT3 radiochromic film.

Results: The minimum and maximum skin doses in a fraction (with 2.0 Gy prescribed dose) were 0.50 Gy and 0.97 Gy, respectively. Based on these values, the total skin dose in 30 treatment fractions (for removed tumor) or in 35 treatment fractions (for unremoved tumor) was in the range of 15-33 Gy.

Conclusion: Based on the skin dosimetry results of parotid cancer radiotherapy using EBT3 films, it is predicted that there will occur mild skin reactions and these reactions can be neglected due to being mild.

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Keywords

Radiotherapy; Parotid; Neoplasms; Skin; Dosimetry; Radiochromic Film

Introduction

Cancer is as one of the main health problems in the USA and other countries worldwide [1]. Among 4 deaths in the USA, one of them is due to cancer [2]. Currently, cancer has been the second cause of mortality in the USA. Moreover, it is predicted that it will be the first cause of death and dominate the death from heart diseases during the next years [1]. Every year, 560000 cases of head and neck cancers are diagnosed worldwide, which 300000 ones led to death. Nasal cavity, mouth, throat and larynx cancer are special types of head and neck cancer. Parotid neoplasm is accounted as 1-3% of malignant head and neck tumors. Surgery is the first way for treatment of primary malignant parotid tumors with small size; on the other hand, combined treatments

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are necessary for advanced tumors, depending on the size of tumor and its metastasis [3].

Both radiotherapy and surgery are the main methods in treatment of malignant parotid tumors, which have characteristics such as end stage, larger than 4 cm, locating at the deep lobe of parotid and involving lymph nodes. In this case, radiotherapy is normally performed using 6 MV photon beam of a medicallinac [4]. Among various treatment modalities, radiotherapy is a preferred method than surgery. While radiotherapy may cause secondary cancers, it is noninvasive and has lower physiologic and mental side effects for patients compared to surgery and pharmaceutical approaches [5].

Since the radiation is not completely focused on tumor in radiotherapy, toxicity is caused in adjacent anatomical structures [6]. In superficial regions, uncertainty of dosimetry has been a main worry in radiotherapy [7]. Suffering to erythema, desquamation and necrosis are routine effects during or following radiotherapy. Epidemiologic studies have reported that there is a relation between radiotherapy and induction of cancer in basal cell carcinoma [8]. These side effects on skin due to radiotherapy are limiting factors for radiation therapy. Therefore, to prevent occurrence of such effects, it is useful to consider skin dose during treatment planning and to measure skin dose.

Skin dosimetry is more complicated for those parts of body located on chest, and head and neck [9]. As an example due to presence of outer ear, the form of target volume and dose distribution is inhomogeneous in treatment of parotid cancer [4]. Due to presence of these curvature structures and in homogeneities, dose calculation is more complex using soft wares. Skin doses obtained from calculations should be compared with those from measurements. Additionally, due to presence of different layers in skin such as dermal and basal layers, and the different depth of these structures layers in various people, International Commission on Radiological Protection (ICRP) recommends a 0.07 mm depth (basal layer) for evaluation of skin dose [8].

Recently, there have been advancements in the use of radiochromic films in evaluation of dose distribution. Various studies have had emphasis on application of these films in the field of radiation dosimetry and quality control of radiotherapy machines [10]. Radiochromic films have been widely used for surface dosimetry. Having appropriate characteristics such as high spatial resolution, low sensitivity to energy spectrum, being tissue equivalent, self-development and concise usage make these films a suitable choice for dosimetry.

Pevic et al. [9] have performed a comprehensive study on surface dosimetry by radiochromic films. They measured percentage depth dose in the first millimeter depth in a water phantom using different radiochromic films and dosimeters. Alashrah et al. [11] evaluated surface dose in a 6 MV photon beam using HS radiochromic film, thermoluminescent dosimeters and Farmer ionization chamber in a water phantom and compared the results with those from surface dose obtained using Monte Carlo simulations. There was good agreement between the surface dose measured by radiochromic film and thermoluminescent dosimeter and those by their Monte Carlo simulations [11]. Nakano et al. [9] measured surface dose in radiotherapy fields of breast cancer using Gafchromic EBT2 and Attix parallel plate chamber. The measurements were performed on cubic and curved phantoms. It was reported that there is a good agreement between the dose measured by Gafchromic EBT2 and parallel plate chamber. Bilge et al. [12] measured surface dose in 6 MV and 18 MV photon beams on a solid water phantom. They also measured surface dose using Gafchromic EBT film and parallel plate chamber. The agreement between the measurements by radiochromic film and parallel plate chamber for 18 MV photon beam was 3.0%. The surface dose results by Gafchromic EBT were 5.0% higher than the values obtained from

parallel plate chamber [12]. There are also other studies on skin dosimetry and skin reactions due to absorption of radiation dose [13-15]. In a study carried out by Bahreyni Toossi et al. [16] EBT and EBT3 radiochromic films were compared in dosimetry in radiotherapy for treatment of parotid cancer.

Their experiments were performed on the 6 MV photon beam of a Siemens Primus linac. Skin dose was measured at different points by these two types of films on a RANDO phantom. There were differences between the dose values from calibration and on-phantom measurements using these two films. EBT film, due to higher sensitivity, demonstrated higher NOD than EBT3 film.

While various studies have been performed on skin dosimetry in radiotherapy of different target regions, to the best of our knowledge, there is not any research on skin dose measurement and skin reactions in parotid cancer treatment. Since the skin reactions can be limiting factors in the radiotherapy process. The aim of the present study is to evaluate skin dose in radiotherapy of parotid cancer. For this purpose, EBT3 radiochromic film is used for skin dosimetry on a RANDO phantom irradiated with 6 MV photon beams in treatment of parotid cancer fields.

Material and Methods

This is an evaluating study in the field of radiotherapy physics. Skin dose was measured in parotid cancer radiotherapy on a RANDO phantom using EBT3 radiochromic film. The first treatment planning, for treatment of parotid cancer, was performed by a clinical oncologist on the RANDO phantom. In the overlapping region of the right anterior-oblique (RAO) and right posterior-oblique (RPO) fields, 9 points were determined for skin dosimetry so that the points cover various regions on the overlapping area. The films were calibrated using 6 MV photon beam of a Siemens Primus linac. Then, the films were attached on the RANDO phantom at the prespecified points for skin dose measurement in the irradiation by the RAO and RPO fields. The skin dose per fraction from these two fields was measured.

Gafchromic EBT3 radiochromic film

Gafchromic EBT3 radiochromic film was commercially introduced by international speciality products on 2011. Based on the manufacturer, the chemical composition of various layers of this film is the same of that of EBT2 radiochromic film [17]. As seen in Figure 1, EBT3 film is composed of a 27 µm thick active layer, and two 125 µm thick polyester layers at the two sides [18]. The chemical composition of various layers of this film are listed in Table 1.

The symmetric geometry of this film is the main difference between this film and EBT2radiochromic film. In other words, this film has the same thickness of polyester layers at the two sides. Therefore, this film can be scanned on its both sides with the same dosimetric responses. There are silica particles in the composition of this film, which prevent Newton fringes artifact in the scanned images of the film [17].

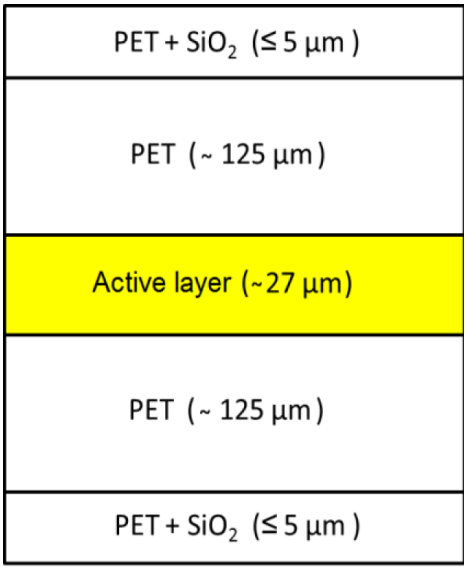

Figure 1: Structure of Gafchromic EBT3 radiochromic film

Table 1: Composition of EBT3 radiochromic film (atomic percentage)

Layer	Density (g/cm^3)	H	Li	C	O	Al
Polyester base	1.35	36.4	-	45.5	18.2	-
Active layer	1.20	56.8	0.6	27.6	13.3	1.6

In the present study, film sheets of 07221303-lot number were used in the calibration and skin dose measurement steps.

Calibration of radiochromic films

A film sheet of EBT3 radiochromic film (lot number 07221303) was cut to 48 pieces of 1.5 × 2 cm^2 films. To maintain a consistent orientation for the film pieces, the film pieces were cut so that their length was along as the longitudinal direction of the film sheet. The film pieces were divided into 12 groups, including 4 film pieces. An identification number was allocated to each film piece.

To obtain background optical density (optical density before irradiation) of the film pieces, they were scanned using a Microtek 1000XL Pro scanner. The films were scanned in transmission mode with 100 dpi resolution in the form of 48-bit RGB images. They were positioned in landscape mode on the central part of the scanner. The Microtek scanner uses Microtek Scan Wizard Pro V7.041 software to scan the films. The film images were saved in the form of TIFF (tagged image file format) files. To minimize the effect of noise in the scanning process, each film was scanned for three times and the average values were used. To stabilize and warm up the scanner, it was turned on at least 0.5 hour before the scanning.

For the purpose of calibration, the Gafchromic EBT3 film pieces were irradiated by a 6 MV photon beam in the range of 0.1 Gy-5.0 Gy doses. In each dose group, 4 pieces of films were irradiated with the same conditions. Each dose group was located at 10 cm depth of a solid water phantom (PTW(RW3)) with dimensions of 30 cm × 30 cm × 30 cm. The source to surface distance (SSD) was 100 cm and the films were irradiated in a 10 cm × 10 cm field using 6 MV photon beam of a Siemens Primus linac at Reza Radiation Oncology Center. The films were read 36 hours after irradiations, as they were scanned for background optical density reading. To obtain the background pixel value (P_B) and pixel value of the irradiated films (P_C), MATLAB (The Math Work, Inc., Natwick, MA version 7.11.0.584) software was used. The films were scanned in the form of RGB images and the red color channel was extracted. Furthermore, those pixels on the edges of the films were excluded in the calculations. Those pixels on regions of interest of 1 cm × 1 cm on the central parts of the films were included for averaging and pixel value calculations. Average pixel values were calculated from 3 times of film scanning's of each film piece. Then, averaging was performed on the 4 film pieces in each dose group.

Net optical density (NOD) is calculated from the following equation:

$$NOD=OD_C-OD_B=-(\log_{10}(P_C)-\log_{10}(P_B)) \quad (1)$$

OD_C is the optical density after irradiation (calibration) and OD_B is the background optical density. The curve of dose (Gy) was plotted versus NOD using MATLAB software. An exponential function was fitted to this curve. The film handling and reading process was based on the recommendations of task group No. 55 (TG-55) of American Association of Physicists in Medicine [19].

Treatment planning on RANDO phantom

Commercially available RANDO phantom (The Phantom Laboratory, Salem, NY) is

made from a skeletal structure and plastic tissue equivalent material. This phantom is composed of 36 slices, with numbers ranging from 0 to 35. The thickness of 0 to 34 slices is 2.5 cm and the thickness of the pelvic base (slice number 35) is about 9 cm. Most of the slices include holes to hold TLD chips for the purpose of in-phantom dosimetry [20].

In the irradiation set-up, the RANDO phantom was positioned on the couch of a Siemens computed tomography machine (Siemens Somatom, Emotion Duo) in Reza Radiation Oncology center (Mashhad, Iran). Computed tomography images with 0.5 cm slices were acquired from the RANDO phantom. Using the images, treatment planning was performed by a commercial Prowess Panther treatment planning system (Prowess Inc., Concord, CA, USA) with designing a right anterior-oblique and right posterior-oblique fields. A clinical oncologist in the aforementioned center performed treatment planning. The characteristics of this treatment planning are listed in Table 2.

Skin dosimetry in parotid cancer radiotherapy fields

For measurement of skin dose using Gafchromic EBT3 radiochromic film in radiotherapy of parotid cancer on RANDO phantom, an oncologist determined the body contours using the CT images of the RANDO phantom. On the overlapping region of the RAO and RPO fields, 9 points were specified for skin dose measurement. The coordination's of such points was determined relative to the marker, as seen in Figure 2. The positions (cm) of these points relative to the marker are listed in Table 3.

An EBT3 film sheet (lot number 07221303)

Table 2: Characteristics of treatment planning in parotid cancer radiotherapy with right anterior-oblique and right posterior-oblique photon fields.

	RAO field	RPO field
SSD (cm)	97.3	97.5
Field size (cm²)	6.4 × 7.0	6.4 × 7.0
Collimator angle (º)	0.0	0.0
Gantry angle (º)	325	237.5
Dose to isocenter (cGy/field)	103.65	104.06
Dose to d_{max}(cGy/field)	104.5	105.2
MU/field	104.3	105

RAO: Right Anterior Oblique, RPO: Right Posterior Oblique, SSD: Sourse to surface distance, MU: Monitor unit

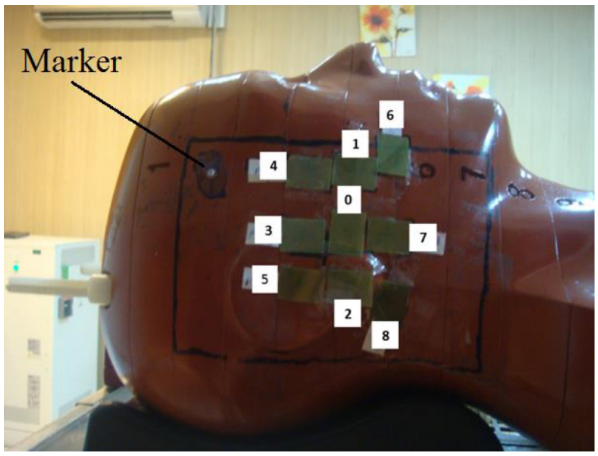

Figure 2: Arrangement of EBT3 radiochromic films on the RANDO phantom in radiotherapy of parotid cancer.

Table 3: Coordination (cm) of the marker and measurement points relative to the marker.

Measurement position	(*x*, *y*, *z*)
Marker	(-6.4, 5.3, -6.4)
P_0	(-6.6, -1.3, -9.0)
P_1	(-6.0, -1.3, -6.0)
P_2	(-7.0, -1.3, -11.2)
P_3	(-7.0, 0.8, -8.9)
P_4	(-6.1, 0.8, -6.0)
P_5	(-7.2, 0.8, -11.0)
P_6	(-5.3, -2.8, -5.2)
P_7	(-6.2, -2.8, -8.9)
P_8	(-6.0, -2.8, -11.9)

from the same batch of the calibration sheet was cut to 1.5 cm×2 cm pieces. The film pieces were divided into 9 groups that each group included two pieces of films. Toread the background optical density, the film pieces were scanned before irradiation, with the same condition of reading in the calibration step. By supervision of the radiation oncologist, and based on the treatment planning, the film pieces were attached to the corresponding points (P_0-P_8) on the RANDO phantom on the overlapping region of the RAO and RPO fields. The RAO and RPO fields were irradiated by 104.5 cGy dose at the d_{max} (at depth of 2 cm from the surface) and 105.2 cGy dose at the d_{max} (at depth of 2 cm from the surface), respectively. The irradiations were performed by6 MV photon beam of a Siemens Primus linac at Reza Radiation Oncology Center (Mashhad, Iran). The irradiation set up, for the RAO and RPO fields, including the relative positions of the linac and RANDO phantom is illustrated in Figure 3. This irradiation was repeated for two times.

As seen in Figure 2, pieces of films were attached on the overlapping region of the RAO and RPO fields at the P_0-P_8 points, and irradiated based on the treatment planning through both fields in a treatment fraction.

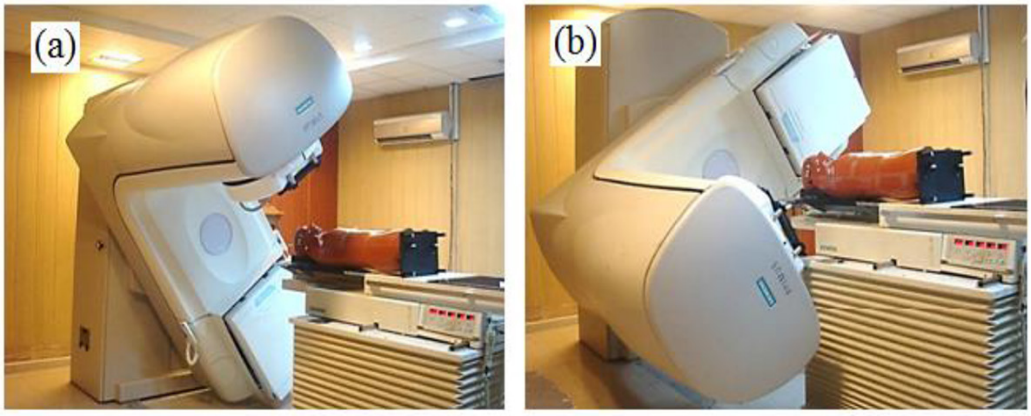

Figure 3: Irradiation setup of the RANDO phantom with right anterior-oblique (a) and right posterior-oblique (b) fields in measurement of skin dose in radiotherapy of parotid cancer.

Each measurement of point was repeated twice with two film pieces. The film pieces were scanned 36 hours after on-phantom irradiations with the same condition of reading as the calibration step. Net optical density of various pixels on the film pieces were determined using MATLAB software, which was the same as that in the calibration step. Next, using the fitting formula, dose values were calculated from the net optical density values.

Results

The net optical density values from calibration irradiation of Gafchromic EBT3 radiochromic film are listed in Table 4. In Figure 4, the calibration curve (dose versus net optical density) is plotted for this film type. The fitting was performed using MATLAB software.

The following equation is the fitting formula for dose (Gy) as a function of net optical density (NOD):

$$D=1.612e^{4.553NOD}-1.582e^{-1.708NOD} \quad (2)$$

The skin dose values (Gy) in one fraction in the overlapping region of right anterior-oblique and right posterior-oblique fields in radiotherapy of parotid cancer are presented in Table 5.

By the skin dose values in one fraction and considering two cases of unremoved tumor

Table 4: Net optical density in EBT3 radiochromic film following calibration with 6 MV photon beam.

Given dose (Gy)	Net optical density
0.1	0.0082
0.3	0.0253
0.5	0.0424
0.7	0.0602
1.0	0.0846
1.25	0.1026
1.5	0.1231
1.75	0.1375
2.0	0.1498
2.5	0.1800
3.5	0.2289
5.0	0.2875

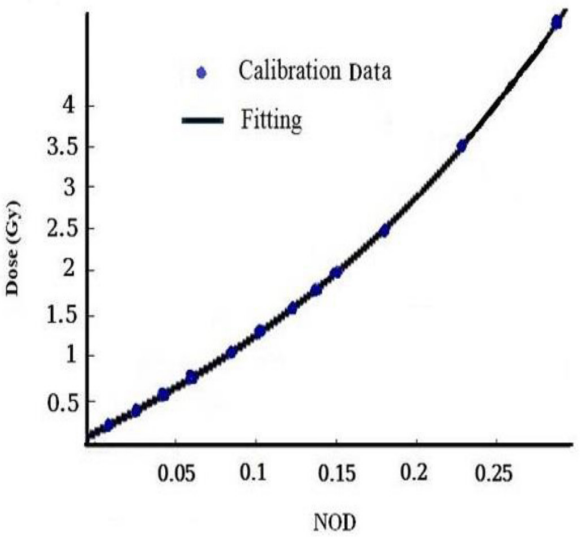

Figure 4: Calibration curve for the EBT3 radiochromic film

and removed tumor, the total skin dose values were calculated. The total skin dose values are presented in Table 6.

Discussion

In the present study, skin dosimetry was performed on RANDO phantom in radiotherapy

Table 5: Skin dose measured with EBT3 radiochromic film in one session of parotid cancer radiotherapy. The values are related to the summation from two fields.

Skin dosimetry point	Measured dose (Gy)
P_0	0.83
P_1	0.61
P_2	0.83
P_3	0.84
P_4	0.56
P_5	0.67
P_6	0.50
P_7	0.88
P_8	0.97

by photon beams in treatment of parotid cancer. Based on the obtained results in Table 5, the maximum skin dose in one fraction is 0.97 Gy, related to point P_8. The minimum skin dose per fraction is 0.50 Gy, related to point P_6. Since the P_1 and P_6 points are in the close vicinity of each other and located near to the fields' boundaries, it is expected that they tolerate relatively the same doses and lower doses compared to the other points.

Various skin reactions following radiotherapy in relation to the received skin dose are presented in Table 7 [21].

Skin dose in one fraction may not be clinically relevant; therefore, total skin dose should be considered during the total treatment period. For parotid cancer radiotherapy, two treatment regimens can be applied, including unremoved tumor and removed tumor. The dose -fraction regime is different for these two cases and the total skin dose in these two cases is discussed in the following.

For the case of unremoved tumor, based on the consultation with an oncologist, the skin dose levels measured on the RANDO phantom at points P_0-P_8 are expectable. Since the

Table 6: Total skin dose following parotid cancer radiotherapy in two cases of removed tumor and unremoved tumor.

Measurement position	Total skin dose (Gy) in 35 fractions (for unremoved tumor)	Total skin dose (Gy) in 30 fractions (for removed tumor)
P_0	29.05	24.90
P_1	21.35	18.30
P_2	29.05	24.90
P_3	29.40	25.20
P_4	19.60	16.80
P_5	23.45	20.10
P_6	17.50	15.00
P_7	30.80	26.40
P_8	33.95	29.10

Table 7: Skin reactions following skin exposure in radiotherapy.

Total dose in a number of fractions (Gy)	Expected effects	Structural changes
~20	Epilation	Hyperemia
20-40	Erythema	
~45	Color change	
~45	Dry desquamation	Serum leakage, healing re-generates functional barrier
45-50	Healing moist desquamation, Vascular legions	
>50	Moist desquamation which does not heal in more than 50% of cases	Loss of protective barrier
>60	Non healing necrosis	Loss of protective barrier

priority in such irradiation is to deliver the treatment dose to the target volume, and the skin tolerance is not a limiting factor with this regard. Based on the values listed in Table 7 and considering the treatment planning details in Table 2, the points P_4 and P_6, which have received dose levels about 20 Gy, will tolerate epilation. Additionally, for the points P_0-P_5, P_7 and P_8 with received doses ranging from 20-40 Gy skin, erythema is predicted.

For the case of removed tumor, P_0, P_3, P_7 and P_8 can be corresponded to the points with surgery scar from the tumor removal surgery. Therefore, it is expected that these points receive the prescribed dose in one fraction. From 2 Gy prescribed dose in one fraction (1 Gy from each the RAO and RPO fields), P_0, P_3, P_7, P_8 receive 0.83 Gy, 0.84 Gy, 0.88 Gy and 0.97 Gy doses, respectively. These results indicate that these points received lower doses than the expected level and bolus can be used to compensate this effect. Considering the

skin dose values in Table 6 and Table 7, P_1, P_4, P_5 and P_6 will tolerate epilation. Furthermore, by considering the received dose in the points P_0, P_2, P_3, P_7 and P_8, it is predicted that skin erythema will be happened at these points. These side effects are mild and do not result to important complications for the patients. To the best of our knowledge, there are not corresponding published results and therefore the results of the present study can not be compared with other studies.

As it was mentioned in the introduction section, Bahreyni Toossi et al. [16] have compared the results by EBT and EBT3 radiochromic films in dosimetry for treatment of parotid cancer in radiotherapy. There are some similarities (photon energy, model of linac, phantom and radiation fields) between the methods applied in that study and the present study. However, the aims and results of the study carried out by Bahreyni Toossi et al. and the present study are quite different. In that study, the skin dose per fraction were compared by EBT and EBT3 radiochromic films; however, in the present study, the total skin dose in parotid radiotherapy was measured and the skin reactions was predicted based on results of the total skin dose. Due to some differences in the methods applied in these two studies, the results can not be compared accordingly.

Conclusion

According to the obtained results of skin dosimetry in parotid cancer radiotherapy, it is predicted that mild skin reactions such as erythema and epilation can occur. The type of these reactions will depend on the skin tolerance and skin color and have variations in various patients. Since the dose delivered to the target volume is of the priority, such mild reactions may not be of importance.

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Conflict of Interest

None

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