TURKISH JOURNAL of ONCOLOGY

Turk J Oncol 2018;33(1):12–7
doi: 10.5505/tjo.2018.1736

ORIGINAL ARTICLE

Investigation of Surface Dose Using Film Dosimetry and Commercial Treatment Planning System for Larynx Cancer Treatment with Intensity-Modulated Radiotherapy and Volumetric Modulated Arc Therapy

Uğur AKBAŞ,[1] Nazmiye DÖNMEZ KESEN,[1] Canan KÖKSAL,[1] Kübra ÖZKAYA,[2] Musa ALTUN,[2] Hatice BİLGE[1]

[1]Department of Medical Physics, Istanbul University Institute of Oncology, Istanbul-*Turkey*
[2]Department of Radiation Oncology, Istanbul University Faculty of Medicine, Istanbul-*Turkey*

OBJECTIVE
Surface dose measurement is challenging, and algorithms of treatment planning systems (TPS) cannot accurately calculate the surface dose. The aim of this study was to investigate the surface dose with radiochromic film measurement and TPS calculation for larynx cancer treatment using intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT).

METHODS
IMRT and VMAT plans for 5 larynx cancer patients were created using TPS. The plans were transferred to a Rando phantom for radiochromic film measurement. TPS calculations and film measurements were compared for surface doses.

RESULTS
TPS underestimated the surface dose for both IMRT and VMAT plans. The average difference between TPS calculations and film measurements were found to be 12.9±6.1% and 12.4±7.7% for IMRT and VMAT, respectively. Surface dose was found to be lower in VMAT technique at all measurement points.

CONCLUSION
TPS have an important role in radiotherapy treatments. Yet, they are still not adequate for dose measurements in shallow depths. Underestimations or overestimations in calculations can occur. The error ratio of TPS, which should be considered while evaluating the radiotherapy plans, can be determined by dosimetric measurements. Radiochromic films are suitable equipments for this process.

Keywords: Film dosimetry; surface dose; treatment planning system.

Introduction

In megavoltage photon beams, the electron contamination of the incident beam causes surface dose, which is defined at the boundary between air and patient. In external beam radiation therapy, accurate knowledge of surface dose may help reduce the risks of acute skin reactions and delayed effects such as erythema, necrosis, desquamation, and dermal lymphatic and basal-cell carcinoma.[1] Also, it is important to know the surface

Received: February 26, 2018
Accepted: February 26, 2018
Online: March 16, 2018

Accessible online at:
www.onkder.org

Dr. Uğur AKBAŞ
İstanbul Üniversitesi Onkoloji Enstitüsü,
Sağlık Fiziği Bilim Dalı,
İstanbul-Turkey
E-mail: u.akbas@yahoo.com

dose in the irradiation of superficial tissues to ensure that the target receives the prescribed dose. Surface dose is mainly contributed by the scattered radiation from materials in the path of the beam, air, and patient.[2] The energy of the beam, the size of the irradiation field, and the source to skin distance are the parameters that directly affect surface dose. The oblique beam incidence and use of beam modifiers such as immobilization devices, bolus, and block tray increase the deposited dose at shallow depths. In most cases, megavoltage photon beams are utilized in radiotherapy. Due to the lack of electron equilibrium, the use of high-energy photon beams result in lower deposited dose at the surface.[3] This steep dose reduction in the surface area is known as the skin-sparing effect. Accurate knowledge of the dose at such shallow depths is required in special measurement techniques and devices.

The measurements of surface and buildup region doses are difficult. Extrapolation ionization chamber is the most accurate dosimetric device to measure doses at shallow depths, but not all institutions have this equipment. Due to their thin entrance window, the fixed-separation parallel plate ionization chambers can be used for surface and buildup region dose measurements instead of extrapolation chamber, but secondary electrons scattering from the sidewall of the chambers cause overresponse. This problem can be solved using Gerbi's correction factors.[4] These chambers can only be used with phantom measurements because of their physical geometry. Radiochromic film is an appropriate dosimeter for surface and buildup region dose measurements with its high spatial resolution and low spectral sensitivity. The characteristics of radiochromic film make it a substantial dosimeter for the regions of steep dose reductions and also make it a good alternative to parallel plate ionization chamber. Bilge et al. [5] utilized EBT2 radiochromic film for surface dose measurements and compared the results with those of a parallel plate ionization chamber. The difference between EBT2 radiochromic film and ionization chamber was found to be within 5% and 3% for 6 MV and 18 MV, respectively. Also, the physical properties of radiochromic films allow in vivo dose measurements.

Treatment planning systems (TPS) use algorithms to calculate dose distributions in irradiation area. Accurate dose calculation for surface and buildup region is a challenge for most commercial algorithms. The dose prediction of TPS at surface and buildup region depends on several factors including calculation algorithm, beam modeling, and linac commissioning. Contaminated electrons induced from a collimator system and secondary photons scattering from the linac head cause contribution to the dose. This contribution is the main reason for the difficulty of dose calculation at superficial regions for algorithms.[6] Previous studies have reported that some commercial TPS underestimate surface and buildup region doses by 10%–30%.[7,8] Calculated doses near the surface obtained by TPS are generally inaccurate due to the lack of electronic equilibrium.[9]

In radiation therapy, surface dose calculation accuracy is important in cases when the target volume is close to the skin. The precision of TPS should be assessed to prevent potential risks of toxicity and to provide acceptable dose coverage to target volumes near the surface. In this study, our aim is to investigate surface dose with radiochromic film measurement and TPS calculation for intensity-modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT).

Materials and Methods

Phantom

A tissue-equivalent anthropomorphic Rando phantom (Alderson Research Laboratories, Stanford, CT) was used for irradiation. Computed tomography (CT) images of the phantom were acquired with head-first supine position using Philips Brilliance Big Bore CT (Philips Healthcare, Cleveland, OH) (Fig. 1). Thermoplastic mask was utilized for head and neck immobilization as it is used for real patients. Slice thickness of 3 mm was chosen for CT scanning. Then, images were sent to TPS to determine the surface dose for IMRT and VMAT techniques.

Planning

In this study, CT images of 5 larynx cancer patients were used to create IMRT and VMAT plans. Slice thickness of 3 mm was chosen for CT images. Targets and organs at risk volumes were defined and contoured by a radiation

Fig. 1. CT images of tissue-equivalent anthropomorphic Rando phantom.

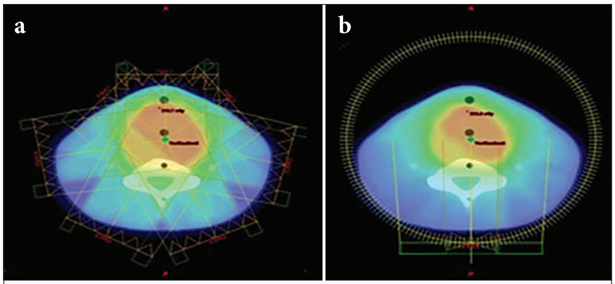

Fig. 2. QA plans of IMRT (a) and VMAT (b) techniques on Rando phantom.

oncologist. Treatment plans were created using Eclipse 8.9 (Varian, Palo Alto, CA, USA) TPS on Varian Trilogy linear accelerator equipped with a 120-leaf MLC, performing 6-MV coplanar photon beams. Analytical anisotropic algorithm (AAA) was utilized for dose calculation. A calculation grid of 2.5 mm was chosen for treatment plans. Doses of 70 and 54 Gy were prescribed for target volumes, and simultaneous integrated boost method was used for each plan with a fraction number of 35. The optimization aim of all plans was that 95% of the target volumes should receive 100% of the prescribed doses.

IMRT plans were generated with 7 coplanar fields, which were separated at 52° apart. Sliding window technique was chosen. A fixed dose rate of 500 MU/min was applied for dose delivery. VMAT plans were created using a dose rate of 600 MU/min, which is the maximum value of the linac. VMAT plans consisted of 2 full arcs rotating from 179.9° to 180.1° counter clockwise and clockwise. Collimator angles were fixed to 30° and 330° to avoid tongue and groove effect. Then quality assurance (QA) plans of both IMRT and VMAT techniques were generated using Rando phantom for irradiations and measurements (Fig. 2). The isocenter of the plans and positions of gantry, collimator, and couch were set to the same as those in plans.

Film dosimetry

Gafchromic EBT3 film (International Specialty Product, NJ, USA), which has a single active layer of approximately 30 μm thickness sandwiched between two 125-μm transparent polyester sheets, was utilized in this study. Compared with older versions of radiochromic films, EBT3 is more sensitive with its wide dose range of 1 cGy to 40 Gy and has symmetric structure that allows scanning on either side.

Before measurements, a calibration curve was created for the film batch. The films cut into 2.5×2.5 cm^2 and placed perpendicularly between the water equivalent slab phantoms at the depth where the linac calibrated 1 cGy equals to 1 MU. Films were irradiated at 0–800 cGy at a field size of 10×10 cm^2. Unirradiated film piece was used as background. The net optic densities (ODs) of the irradiated films were corrected to the known doses to create the calibration curve, which was used for converting net ODs to absolute doses in measurements.

Fig. 3. EBT3 film placement on Rando phantom for measurement.

EBT3 films were put on the surface of the center of the larynx (Fig. 3). Irradiation was performed with treatment fields of IMRT and VMAT plans using 6-MV photons beams. Films were scanned 24 hours after irradiation. The calibration of the film batch was used to acquire absolute doses.

TPS calculation

In this study, AAA was performed for treatment plan calculations. AAA has 3 source models including primary photons, scattered extra-focal photons, and contaminated electrons from beam-limiting devices such as collimators. The algorithm accounts the heterogeneities anisotropically using lateral photon scatter kernels. The electrons generated through Compton scattering from the linac head and air were modeled by the electron contamination source, which utilizes a depth-dependent curve defining the dose from lateral electron contamination. This source has a major role in surface and buildup region dose calculation. The dose distributions are acquired by superposition of doses from electron and photon convolutions in AAA.[10,11]

Table 1 The results and differences of TPS calculations and film measurements for surface dose in IMRT technique

	IMRT		
Patients	**Eclipse TPS (cGy)**	**EBT3 film (cGy)**	**Difference (%)**
1	133.1	160.8	-17.2
2	70.2	82.6	-15.0
3	70.0	81.6	-14.2
4	50.4	51.5	-2.2
5	58.6	69.6	-15.8

Average difference±Standard Deviation: -12.9±6.1
Median (Min – Max): -15.0 (-17.2 – (-2.2))
$p<0.05$.

Table 2 The results and differences of TPS calculations and film measurements for surface dose in VMAT technique

	VMAT		
Patients	**Eclipse TPS (cGy)**	**EBT3 film (cGy)**	**Difference (%)**
1	127.7	140.6	-9.2
2	52.9	53.6	-1.3
3	77.4	90.3	-14.3
4	28.1	36.2	-22.2
5	41.9	49.2	-14.9

Average difference±Standard Deviation: -12.4±7.7
Median (Min – Max): -14.3 (-22.2 – (-1.3))
$p<0.05$.

Table 3 Percentage depth doses (%DDs) of 6-MV photon beam for 10×10 cm^2 open field

Depth (mm)	Eclipse TPS (%DD)	EBT3 Film (%DD)
0	11.0	20.4
1	42.2	48.0
2	54.5	61.3
5	79.9	87.6
10	95.8	99.2
15	100.0	100.0

The location of the point which was on the surface of larynx used in film measurements was determined for IMRT and VMAT plans in TPS. Then, surface doses calculated using AAA were obtained from TPS. The results of the calculations were then compared with film measurements.

Open field irradiation

A comparison between film measurements and TPS calculations was also made for open field. Surface and buildup region doses were measured and calculated in a field size of 10×10 cm^2 using water equivalent slab phantoms for 6-MV photon beams. A phantom set with a thickness of 15 cm was prepared for CT scanning. CT images were sent to TPS for open field calculation. The same phantom set with 2.5×2.5 cm^2 film piece on the top of it was irradiated under the same conditions as in the TPS. The results were then compared.

Results

The results and differences of the Eclipse TPS calculations and Gafchromic EBT3 film measurements for surface dose in IMRT and VMAT techniques are shown in Table 1 and Table 2, respectively. Surface doses obtained from film measurements were found to be higher in IMRT plans compared with TPS calculations with an average difference of 12.9%, and the median of the difference was 15.0%. Surface doses acquired from film measurements were also found to be higher in VMAT plans than in the TPS calculation with an average difference of 12.4%, and the median of the difference was 14.3%.

Statistical Package for the Social Sciences version 11.0 software (IBM, Chicago, IL, USA) for Windows was performed for statistical data management and analysis. The Wilcoxon signed-rank test was applied to determine statistical significance with p-values of <0.05 considered to be significant. The surface dose differences between TPS calculations and film measurements for IMRT and VMAT techniques were found to be statistically significant.

The comparison of TPS calculation and EBT3 film measurements for surface and buildup region doses at 10×10 cm^2 open field at 0, 1, 2, 5, 10, and 15 mm were made to evaluate the results of IMRT and VMAT techniques. The results are given in Table 3. The obtained PDDs show that doses calculated by TPS are lower than film measurements at shallow depths.

Discussion

Dose measurement at the surface and buildup region is challenging. The physical properties of dosimeters make surface dose measurements more difficult. Accurate knowledge of doses near surface area is helpful in making clinical decisions such as determining the prescribed dose, especially in cases where the skin is defined as a target or a dose-limiting volume. Acute reactions and delayed toxicities can be prevented by avoiding overirradiation of the skin. The chosen energy for irradiation, size of the field, obliquity of the beam, and complexity of the planning directly affect the surface dose. These parameters also affect the ratio of electron contamination, which has a major role in surface dose occurring and is difficult to calculate with TPS.

Intensity-modulated techniques such as IMRT and VMAT are commonly used in head and neck cancer radiation therapy. In this study, 7-field IMRT and double-arc VMAT plans were generated for 5 larynx cancer patients in Eclipse TPS using AAA, and QA plans were created using Rando phantom for film measurements. The comparison between measurement and calculation was also made at 10×10 cm^2 open field using water equivalent slab phantoms. Surface dose was found to be lower in TPS calculations for both IMRT and VMAT techniques compared with radiochromic film measurements. The average difference between the calculations and measurements were found to be 12.9±6.1% and 12.4±7.7% for IMRT and VMAT, respectively. The open field measurement and calculation gave closer results for the surface and buildup region dose in the first few millimeters of the phantom. It is assumed that the complexity of the treatment fields used in IMRT and VMAT increased the difference between measurement and calculation.

It has been reported that the Eclipse calculation for doses near surface area has a deviation of ±20% in 95% of all measurement points.[12] Akino et al. [13] compared the radiochromic film measurements with AAA calculations for different radiotherapy techniques including IMRT in breast cancer treatments and found that the calculation algorithm underestimated the doses near the surface by 15%–30%. They also reported that the et al. [14] pointed out that an increase in dose uniformity might result in the reduction of surface dose. Another study explained that the dose distributed around the target causes lower doses at the surface.[15] Almberg et al. [16] investigated superficial doses for conventional tangential and intensity-modulated techniques and found that the surface dose was reduced by 20% in multiple-field IMRT technique. The results of our study are consistent with those of the literature; surface doses were found to be lower in VMAT than in IMRT, although some investigators found more accurate results with AAA compared with older algorithms such as pencil beam convolution.[9,17] Also, Chakarova et al. [15] studied superficial dose distribution in breast radiotherapy using tangential beams. They evaluated the Eclipse algorithms performing Monte Carlo calculation and reported that the AAA calculation and Monte Carlo calculation showed agreement within 3% dose/4 mm spatial tolerance.

Polednik et al. [18] investigated various TPS and found that the collapsed-cone algorithm underestimates the surface dose by 20%. Chow et al. [19] studied the accuracy of superposition/convolution algorithm for oblique photon beams using Monte Carlo calculation and reported that AAA and collapsed-cone algorithms cannot accurately calculate the dose below 2 mm. In our study, dose measurements for IMRT and VMAT were made at the surface of the phantom and TPS underestimated the dose by up to 22.2%. Akino et al. [13] explained that the dose calculation accuracy at shallow depths depend on calculation grid size. In their study, 1×1 mm^2 grid size improved the dose inaccuracy from 19.1% to 12.0% compared with 2.5×2.5 mm^2 grid size in IMRT treatment plans. We used 2.5×2.5 mm^2 grid size for IMRT and VMAT plan calculation as we used in clinical practices to evaluate surface doses in our daily routine.

The uncertainties of Gafchromic EBT films ranging up to 7% and the heterogeneities occurred from interlot and intrasheet of Gafchromic EBT films were reported by previous studies.[20,21,22] The films were utilized from the same batch and they were evaluated using the same calibration curve to avoid these uncertainties. Devic et al. [2] measured skin dose for 6-MV photon beams in clinical applications using Gafchromic dosimetry films (HS, XR-T, and EBT), and they reported that even a small thickness of Gafchromic EBT film might cause an increase in the surface dose. In our previous study [23], Gafchromic EBT3 film gave similar results with Markus parallel plate ionization chamber, which is assumed to be the most accurate dosimeter for surface dose measurements after extrapolation ion chambers. In this study, film results were used as reference.

The surface doses should be measured for verification of radiotherapy plan. In this study, the film dosimetry, which is an appropriate and easy method to determine the dose at surface, was utilized with Rando phantom.

Conclusion

Nowadays, in head and neck cancer patient treatment, higher doses to the target volumes can be delivered using intensity-modulated techniques such as IMRT and VMAT. The accurate knowledge of the surface dose is important to avoid toxicities caused by radiotherapy. The algorithms of TPS cannot accurately calculate the surface dose. In our study, surface doses were found to be lower in TPS calculations compared with film measurements. The underestimation/overestimation ratio of TPS should be considered while evaluating the radiotherapy plans. This ratio can be determined by dosimetric measurements. Radiochromic films are suitable equipments for this process.

Peer-review: Externally peer-reviewed.

Conflict of Interest: None declared.

Authorship contributions: Concept – U.A., H.B.; Design – U.A., H.B.; Supervision – U.A., H.B.; Materials – U.A.; Data collection &/or processing – U.A., N.D.K., C.K., K.Ö.; Analysis and/or interpretation – U.A., M.A., H.B.; Literature search – U.A., N.D.K.; Writing – U.A.; Critical review – U.A., M.A., H.B.

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