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Investigation of the effects on dose calculations of correction-based algorithms in different tissue medium

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Abstract

The aim of this study is to investigate the effects of Modified Batho and Equivalent Tissue-Air Ratio (ETAR) correction-based algorithms on dose distributions in the inhomogeneous media and left-sided breast and lung cancer. Distribution profiles at lateral depth and percentage depth dose (PDD) values were obtained for soft tissue, bone and air rectilinear virtual phantoms in the Eclipse treatment planning system (TPS). In addition, intensity modulated radiotherapy (IMRT) treatment planning technique was applied to 20 patients with left-sided breast and lung cancer diagnosis on computed tomography (CT) sections. The maximum dose, mean dose, D_{95}, Monitor Unit (MU) and segment numbers in planning target volume (PTV) were calculated. Although the effect of correction-based algorithms on (PDD) values and dose distribution profiles in lateral depth were calculated below 1% in soft tissue virtual phantom, dose profiles were obtained as approximately 20% in bone and air media. No statistical differences were observed in dosimetric parameters except for PTVmean and D95 values due to the differences in correction-based algorithms in left-sided breast IMRT treatment planning ($p>0.05$). However, significant statistical differences were obtained in the values of lung IMRT treatment plans ($p<0.05$). It was concluded that correction-based algorithms in the different inhomogeneous mediums have a significant effect on the dose values calculated in TPS.

Keywords: Radiotherapy, inhomogeneous medium, correction methods, dose calculation, pencil beam convolution.

1. Introduction

Human anatomy is heterogeneous and has tissue and air spaces with different physical density values. These tissues and organs have different electron density, atomic number, and mass density. Ionizing X-ray passing through the patient can pass through air spaces, lungs, bones and soft tissues [1]. These different inhomogeneous structures cause changes in the transport of photons and electrons and the absorption of the dose. To determine more accurately absorbed dose in irradiated tissues, precise dose calculations are required in inhomogeneous structures [2]. Dose distributions obtained in heterogeneous medium without water equivalent change depending on the energy of radiation and the physical properties of the medium [3].

Percentage depth dose (PDD) and isodose curves used in dosimetric procedures in radiotherapy are obtained from water or water equivalent homogeneous medium. Various methods and algorithms are developed and used in treatment planning systems (TPS) to precisely calculate and correct these changes due to physical parameters in dose distribution [4]. The dose distribution that occurs in the patient's body during radiotherapy treatment is determined by dose calculation algorithms in TPS. Correct dose calculation of algorithms is a very important factor for success in radiotherapy [5].

Correction-based dose calculation algorithms used in TPS make dose calculations by interpolating and extrapolating the depth-dose curves measured in the water phantom and dose profiles taken at various depths.

Celal Bayar University Journal of Science
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Dose distributions are calculated with standard measurements and correction factors [6]. Correction-based algorithms are stated that are not suitable for stereotactic treatments with small treatment fields. In regions with tissue heterogeneity, they may cause inaccurate dose calculations in the target volume and surrounding healthy tissues [7]. In addition, the dose distributions calculated in the radiotherapy treatment plans are based on the correction of the measurements previously obtained in the water phantom. Many correction factors are applied to accurately calculate the patient dose [8]. Power Law (Batho) method, tissue-air ratio method (TAR), equivalent tissue-air ratio (ETAR) method are the main inhomogeneity correction methods. These methods are based on measurement data and precise dose calculation principles [9, 10]. The Pencil Beam Convolution (PBC) algorithm used in calculating photon dose distributions in TPS calculates by convolution of kernels defined as the stored dose around the primary photon pencil beam. It considers inhomogeneous structures using a correction factor such as the Modified Batho, ETAR method [11]. In this study, dose distributions for different inhomogeneous media and tissues were obtained in Eclipse TPS, where the PBC dose calculation algorithm was used. Using these correction-based algorithms, the calculation and comparison of dose values were performed in different treatment fields [12].

The purpose of this study is to dosimetrically compare the effects of different correction-based algorithms on dose distributions in lung ve breast inhomogeneous tissues using PBC dose calculation algorithm and to determine which method would be more appropriate to use in TPSs.

2. Materials and Methods

In this study, dose values for soft tissue, bone and air media s on the rectilinear phantom in Eclipse TPS were primarily examined before obtaining different dosimetric parameters in breast and lung treatment planning. In TPS, different correction-based algorithms were used in soft tissue and inhomogeneous medium, including Modified Batho, Equivalent Tissue-Air Ratio (ETAR) and "none" when the inhomogeneity correction method was not used, and dose calculations were achieved. Before comparing the effects of correction-based algorithms on dose distributions for the PBC dose calculation method in TPS, dose distribution profiles obtained in the inhomogeneous medium were obtained in virtual phantoms and dose calculations were performed. In $V_{8.9.08}$ version (Varian, USA) Eclipse TPS, under 2 homogeneous 25x2x25cm^3 cubic phantoms, 25x9x25cm^3 soft tissue, bone and air materials were defined separately for Hounsfield Unit (HU) values and three rectilinear virtual phantoms were created (Figure 1).

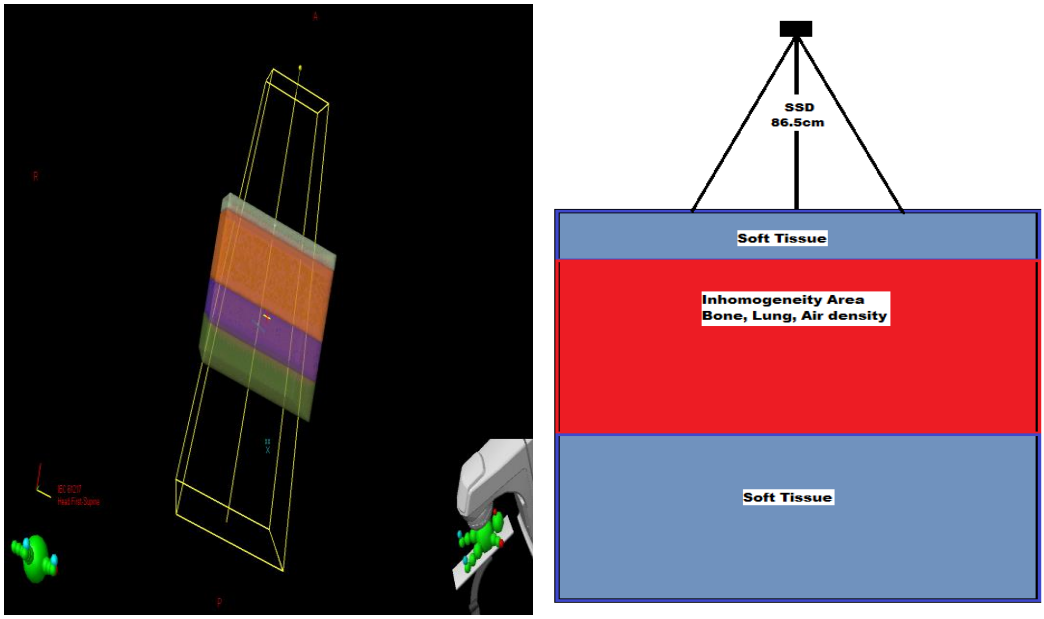

Figure 1. Rectilinear virtual phantom consisting of 25x9x25cm^3 soft tissue, bone and air materials under 2 homogeneous 25x2x25cm^3 cubic phantoms.

Celal Bayar University Journal of Science
Volume 17, Issue 3, 2021, p 305-311
Doi: 10.18466/cbayarfbe.841547

Rectilinear virtual phantoms were created by defining the Hounsfield Unit (HU) and density (g/cm^3) values in Table 1, and their effects due to the difference in density compared to water in the medium in high and low-density medium transitions were shown.

Table 1. Hounsfield Unit and medium densities of homogeneous and inhomogeneous virtual phantoms.

Medium	*Hounsfield Unit (HU)*	*Density (g/cm^3)*	Ratio by Water
Soft Tissue (Water equivalent)	0	1.000	1.0
Air	1000-	0.0012	1/800
Lung	740-	0.2-0.3	1/5
Bone	600+	1.6	1.6X

While creating the set-up phase, phantoms on bone, lung, air, and soft tissue-like material formed the build-up region and were placed to maintain an electronic-equilibrium condition. Other phantoms 10cm thick were placed due to backscattering. All calculations were made on heterogeneous virtual phantoms with 18MV photon energy, Gantry: 0° irradiation angle, 20x20cm^2 beam field size, 2Gy dose and skin source distance (SSD) 86.5cm. In inhomogeneous media where PBC dose calculation algorithm is used, Modified Batho, Equivalent Tissue-Air Ratio (ETAR) and "none" situations; percentage depth dose (%) and dose distribution profiles at lateral depth were calculated and compared in three separate phantoms.

To examine the effect of different inhomogeneity correction methods on the dose distribution in the plans calculated with PBC, Modified Batho plans were copied without any changes, and the plans were obtained by calculating them separately with the ETAR and "none" inhomogeneity correction-method. In order to reveal the effects of correction-based algorithms on dose distributions in different tissues, dose simulation was performed using intensity modulated radiotherapy (IMRT) treatment technique in 20 patients with left-sided breast (50Gy/25fr) and lung (66Gy/33fr) cancers. The maximum dose, mean dose, D_{95}, Monitor Unit (MU) and segment numbers in planning target volume (PTV) were calculated and compared. Later, IMRT based Modified Batho plans were copied without any changes, and the plans were obtained by calculating them separately using the ETAR and "none" inhomogeneity correction method.

3. Statistical Analysis

Analysis of the data was obtained using the SPSS 25 package program. Differences between dose calculation algorithms in terms of mean ± SD measurement values were performed using the independent sample t-test. Differences were considered significant when the p value was <0.05.

4. Results and Discussion

In Figure 2-4, dose distributions at lateral depth and PDD profiles depending on the depth were calculated separately in soft tissue, air and bone media using different dose correction-based algorithms in the rectilinear virtual phantom. In dose calculations performed on soft tissue phantom, the effect of correction-based algorithms on dose distributions were calculated below 1% in PDD values depending on the depth and dose distribution profiles at lateral depth. However, dosimetric differences due to correction-based algorithms were obtained about 20% in PDD values and dose distribution profiles at lateral depth in dose calculations using air and bone media.

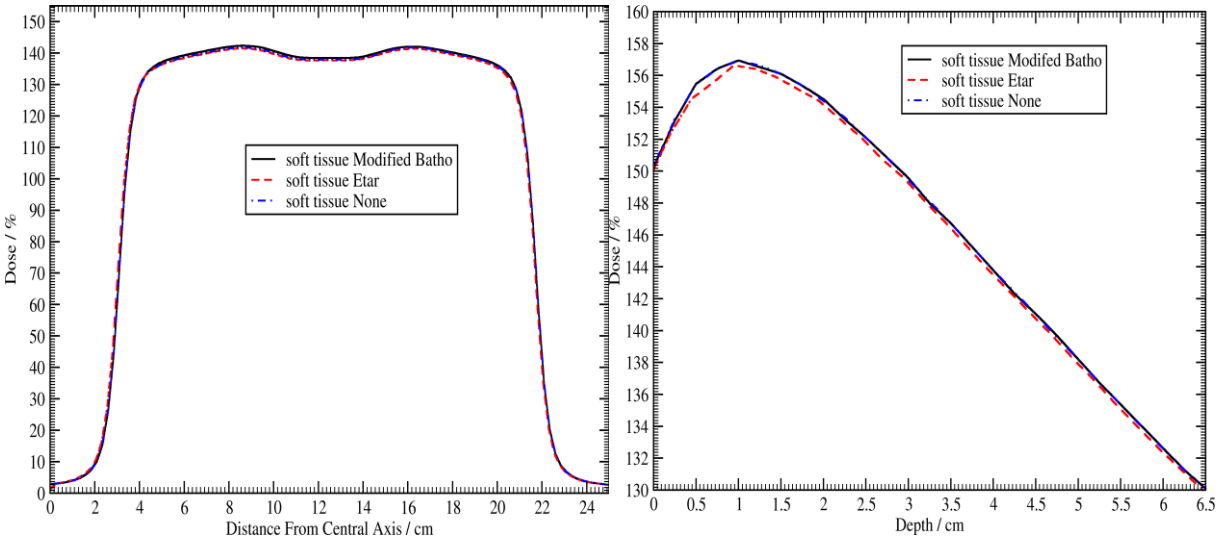

Figure 2. Dose distributions at lateral depth and dose distribution profiles depending on the depth obtained in soft tissue by using different dose correction based algorithms in rectilinear virtual phantom.

Celal Bayar University Journal of Science
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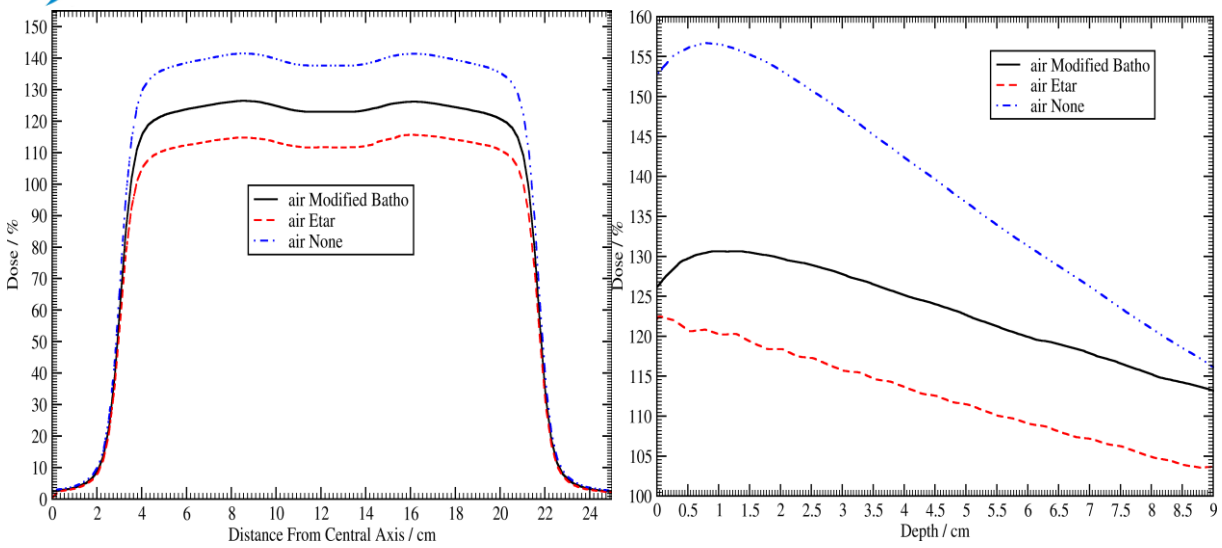

Figure 3. Dose distributions at lateral depth and dose distribution profiles depending on the depth obtained in air medium by using different dose correction based algorithms in rectilinear virtual phantom.

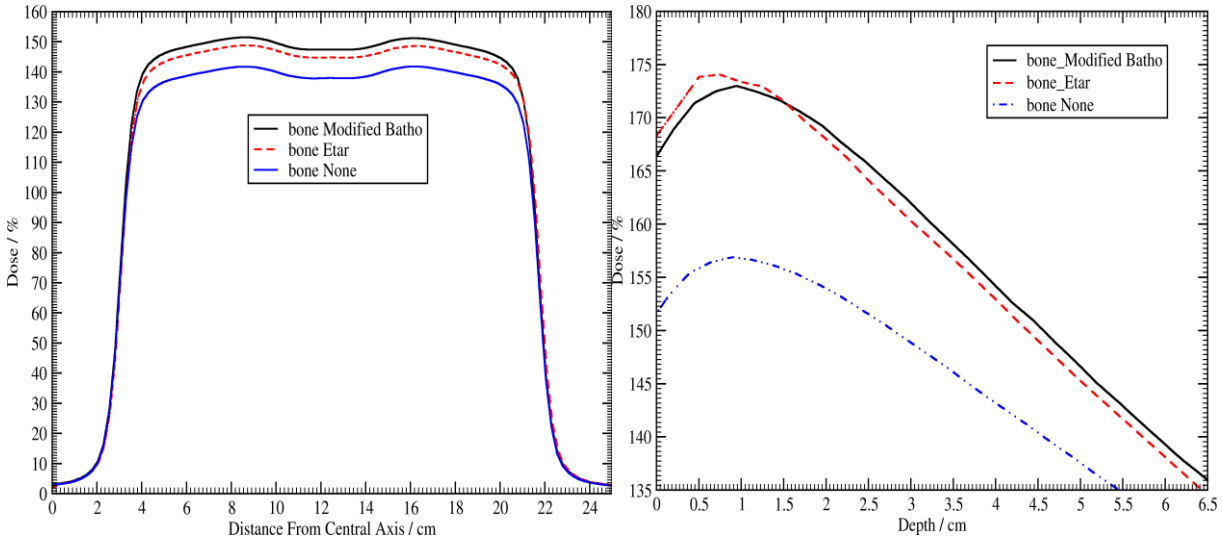

Figure 4. Dose distributions at lateral depth and dose distribution profiles depending on the depth obtained in bone medium by using different dose correction based algorithms in rectilinear virtual phantom.

In dose simulations based on correction-based algorithms performed on computed tomography sections of 20 patients with left-sided breast and lung cancer, dosimetric differences of <2% in breast IMRT treatment technique were obtained in the maximum dose, mean dose, D_{95} in PTV, MU and segment numbers, while lung IMRT treatment technique was calculated an average of 1-10% dose differences in these dosimetric parameters. Although no statistically dose differences were observed in dosimetric parameters (except PTVmean and D_{95} values) due to the differences of correction-based algorithms in left-sided breast IMRT treatment planning ($p>0.05$) (Table 2), significant statistical differences were obtained in the values of lung IMRT treatment plans ($p<0.05$) (Table 3).
Organ doses in external radiotherapy are calculated with the dose calculation algorithms in TPS and it is assumed that they are close to the actual dose distribution between the measurement data loaded into the system and the calculated dose. Different correction-based algorithms are used to obtain the closest dose calculations to reality in patient dose procedures using computed tomography in TPS [13].

The fact that the dose calculated in TPS's is slightly different from the dose administered to the patient is directly related to the capabilities of dose calculation algorithms in inhomogeneous structures.

Table 2. Left-sided breast treatment plan values obtained for different correction-based algorithms

Left sided breast (50Gy/25fr)	PTV Max mean±SD	PTV Mean mean±SD	PTV D_{95} mean±SD	Total MU mean±SD	Segment Number mean±SD
Modified Batho	109±1.8	5107±14.7	4885±12.4	580±12.8	113±5.4
ETAR	109±2.8	5048±18.3	4789±19.8	574±10.7	113±3.9
None	108.8±2.3	5078±11.1	4827±23.4	583±11.5	112±6.5

p Value

	M.B. vs. Etar	M.B. vs. None	Etar vs. None
PTVmax	>0.05	>0.05	>0.05
PTVmean	**0.012***	**0.007***	**0.002***
PTV D_{95}	**0.023***	**0.002***	**0.005***
MU	>0.05	>0.05	>0.05
Segment Number	>0.05	>0.05	>0.05

*****Statistically significant values ($p<0.05$), **MU:** Monitor Unit, **PTV:** Planning target volume, **D_{95}:** Dose covering 95% of the volume, **M.B:** Modified Batho, **SD:** Standard deviation*

Table 3. Lung treatment plan values obtained for different correction-based algorithms

Lung (66Gy/33fr)	PTV Max mean±SD	PTV Mean mean±SD	PTV D_{95} mean±SD	Total MU mean±SD	Segment Number mean±SD
Modified Batho	106±2.3	6357±22.6	6094±15.4	564±13.2	94±7.8
ETAR	108±2.1	6380±18.7	6116±32.2	591±19.8	104±6.5
None	116.5±2.8	6441±15.8	6011±54.7	659±20.7	102±6.9

p Value

	M.B. vs. Etar	M.B. vs. None	Etar vs. None
PTVmax	>0.05	**0.041***	**0.018***
PTVmean	>0.05	**0.017***	**0.007***
PTV D_{95}	>0.05	**0.004***	**0.013***
MU	>0.05	**0.022***	**0.004***
Segment Number	>0.05	>0.05	>0.05

*****Statistically significant values ($p<0.05$), **MU:** Monitor Unit, **PTV:** Planning target volüme, **D_{95}:** Dose covering 95% of the volume, **M.B:** Modified Batho, **SD:** Standard deviation*

Different correction-based algorithms have advantages and disadvantages against each other due to the different dose values obtained in low and high-density heterogeneous mediums such as soft tissue, lung, air and bone [14]. Correction-based algorithms are mainly based on measured data obtained from the cubic water phantom. The total dose at any point is usually obtained by summing up its primary and scatter components calculated separately [15]. The accuracy of correction-based algorithms is limited, especially for 3-D heterogeneity corrections in lung and tissue-cross sections where electronic-equilibrium cannot be fully achieved [16]. Actual dose values in different tissues are found by taking into account some correction factors such as tissue inhomogeneity. Dose calculation algorithms calculate dose by interpolating between depth doses measured in the water phantom and use dose profiles taken at various depths [17]. In TPS-based dose calculation algorithms, it is important to correctly determine the electronic equilibrium perpendicular and parallel to the beam direction to calculate the total absorbed dose correctly. Vertical electronic-equilibrium is especially important in treatment planning for cases where tissue heterogeneity is intense such as lung and breast. In these treatment fields, vertical electronic-equilibrium cannot be calculated effectively due to the fact that TPS algorithms have many heterogeneous in area close to the skin. Therefore, the calculated dose in the skin area is slightly different from the measured dose [18]. The PBC dose calculation algorithm calculates the absorbed dose faster because it does not effectively account for the horizontal electronic equilibrium and scattered electrons. Although vertical electronic equilibrium has been determined, dose calculation accuracy is especially more limited than other dose calculation algorithms in the heterogeneous medium [19].

In this study, no significant dose difference was calculated between the PDD profiles depending on the depth and the dose distribution profiles at the lateral depth in the dose calculations of soft tissue virtual phantoms using different correction-based algorithms. However, we showed that there are significant dosimetric differences in both the depth-dependent PDD distribution profiles and the lateral depth dose distribution profiles in dose calculations using air and bone virtual phantoms. Inhomogeneity correction is required to accurately calculate dose distributions in radiotherapy applications where heterogeneity is dominant, such as lung, breast, head&neck and esophageal cancer.

M. Bragg et al did not observe a significant difference in prostate and head and neck in the study in which they compared the effect of Anisotropic Analytical Algorithm (AAA) and PBC algorithms on dose distribution in lung, prostate and head and neck cancers, but reported significant dose differences in lung cancers [20]. Knöös et al acquired plans with conformal or conventional techniques and compared the results of AAA convolution/superposition algorithms and PBC inhomogeneity correction algorithms in patients with lung, prostate, head-neck and breast cancer. While no significant difference was reported in the prostate and head and neck regions, a significant difference was reported in the lung and breast plans in the neighborhood of low-density inhomogeneous tissue. In addition, these two algorithms were compared with Monte Carlo and it was noted that convolution/superposition algorithms were more compatible with Monte Carlo. They emphasized that the use of IMRT technique may cause new problems [21]. It is desirable that the homogeneous distribution of the dose in the PTV and the dosimetric parameter values should be close to each other for different correction-based algorithms in radiotherapy planning.

Although only statistical differences were observed in mean and D_{95} values in PTV between Modified Batho, ETAR and "none" correction-based algorithms for IMRT plans with 20 left-sided breast cancer diagnoses in this study, significant statistical differences were obtained in all other dosimetric parameters except segment numbers in lung IMRT plans. In addition, we think that the Modified Batho correction-based algorithm can give more accurate results in dose calculations of inhomogeneous structures and in dose distribution profiles depending on depth and lateral depth. Considering the literature studies [22, 23], it was observed that different correction-based algorithms using the PBC dose calculation algorithm were especially insufficient in media where the heterogeneity of the tissue such as lung and bone is dominant and much more complex IMRT treatment planning technique.

We think that it should be compared dosimetrically with dose calculation algorithms such as Monte Carlo, AAA and Acuros, as well as PBC dose calculation algorithm to obtained much more precise and accurate patient dose calculations. In addition, it was concluded that the most ideal patient dose treatment plan can be achieved by using appropriate correction-based algorithms according to the treatment plan.

5. Conclusion

It was concluded that the Modified Batho correction-based algorithm can give more accurate and precise results in dose calculations of such structures in anatomical regions where inhomogeneity is dominant such as head-neck and lung cancer, where the PBC dose calculation algorithm is used.

Author's Contributions

Serhat Aras: Drafted and wrote the manuscript, performed the experiment and result analysis.

Ethics

Ethics committee approval was given by University of Health Sciences Turkey, Hamidiye Scientific Research Ethics Committee.

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