Cumhuriyet Sci. J., 44(3) (2023) 590-594
DOI: https://doi.org/10.17776/csj.1061321

Cumhuriyet Science Journal

| csj.cumhuriyet.edu.tr | Founded: 2002 ISSN: 2587-2680 e-ISSN: 2587-246X Publisher: Sivas Cumhuriyet University

Comparison of Proton and Photon Radiotheraphy for Left-sided Breast Cancer via Dosimetric Calculations

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Research Article

History
Received: 21/01/2022
Accepted: 31/07/2023

ABSTRACT

Breast cancer is the most common type of cancer in women. Today, the radiotherapy method is widely preferred to treat cancer patients where proton therapy is a radiotherapy method used to destroy cancerous cells using proton beams with unique characteristics. Photon therapy, on the other hand, is a classical radiotherapy method that treats cancerous cells by targeting ionizing radiation. In our study, a tumor was placed in the left breast in a water phantom with the help of the Geant4 simulation program and geometry with critical organs was modeled. With this simulation, the doses received by the organs were interpreted and comparisons were made using the chi-square method as the two different source beams, proton and photon deployed. When the percentile values in the dose table are normalized for 1 Gy, the test statistic obtained as 0.467, and the H_0 hypothesis is rejected at the $\alpha = 0.975$ Statistically, we measured the significant differences between proton and photon dose values for tumors and other organs by Geant4 simulations.

Keywords: Breast cancer, Proton therapy, Photon therapy, GATE, Monte Carlo.

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Introduction

Recently, cancer has taken place on the top among health problems all around the world. It is seen that breast cancer is one of the cancer types that affect the health of women in many countries. The increase of cancer cases has led to a rise in the variety of diagnoses and treatments of cancer therefore radiotherapy is the most important factor for breast cancer. [1] Breast cancer radiotherapy aims to protect by giving a minimum dose to healthy tissues while creating a homogeneous dose distribution in the target volume [2] In photon radiotherapy, while the rays are moving through the living tissue, they are scattered by Compton scattering and when they reach the cancerous area, leaving most of their energy on the healthy tissue means that they have destroyed the healthy tissues. In proton radiotherapy, higher doses can be given to the cancerous area in a controlled manner and minimal damage to the healthy tissue can be achieved. Therefore, the use of protons in therapy has come to the fore. The large masses of the protons reduce the scattering in the tissue, so it focuses on the tumor without scattering too much and the healthy tissue is not damaged too much. Protons with energies in the range of 70-250 MeV are used in proton therapy. [3] Geant4-based GATE, a Monte-Carlo simulation software, is being developed by CERN, which has extensive physics resources and is a package program that can provide researchers with ease of analysis. It has been developed in many scientific fields such as modern physics, nuclear physics, radiation physics, nuclear physics. [4] It is important to make the necessary planning to leave the maximum of the radiation energy on the tumor and to give minimum damage to the surrounding healthy tissues, which is the most important factor in radiotherapy using the GATE program. [5]

The outline of the article is as follows: We will describe anthropomorphic phantom simulation in the next section using the GATE software. We will talk about algorithms and dose values obtained with GATE software. In the result part, the Pearson Chi-Square method has been used for analysis study of dozen data and tumor that has been obtained with a software of GATE. In the last part, we will explain the interpretation and result of our study.

Materials and Methods

Anthropomorphic Phantom Preparation with GATE v.9.8

The name Geant is formed by combining the words "Geometry and Tracking. It is a C++ program-based code library developed by CERN, which has an extensive physics library containing tools that can simulate the passage of all kinds of particles through matter and their interaction. [6] It is through macros that we can shape the simulation. In the GATE program, operations such as visualization, applying geometry, identification of physical variable, random number, simulation running hours , or number of participles are created by writing specific codes in Macro files. [7]

Geometry definition is the first step in defining simulation. World geometry, which we have determined as 2.1 m in X, Y, and Z coordinates, is created in the Cartesian coordinate system. Phantom data, created by Medical Internal Radiation Dose Committee, is utilized to simulate human body anatomy and determine the dose absorbed by animals. Whereas Human phantom, 1.70 m tall and 70 kg weight, indicates 20 or 30 years old adult, female phantom data has been utilized. [8] Using the phantom data created by MIRD, organs such as left and right breasts, tumor, heart, brachial plexus, skull, brain, thyroid, lungs, pancreas, stomach, and liver were defined. An adult woman with cancer of the left breast was created in our phantom. The tissues selection is defined as gate/…./setTissue according to the user. In GATE simulation, the physics list was designed as hadronic processes and was added to the physics list by defining it in the format /gate/physics/addPhysicList. Source designation can be defined in the format /gate/source/addSource. Proton and photon rays were determined as the source type. Afterward, the results of the information recorded by the actors which are added to the skin are filed.

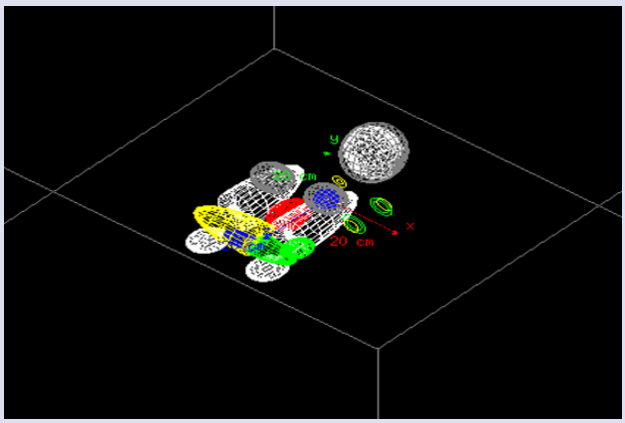


Figure 1. A view from the phantom we made in GATE

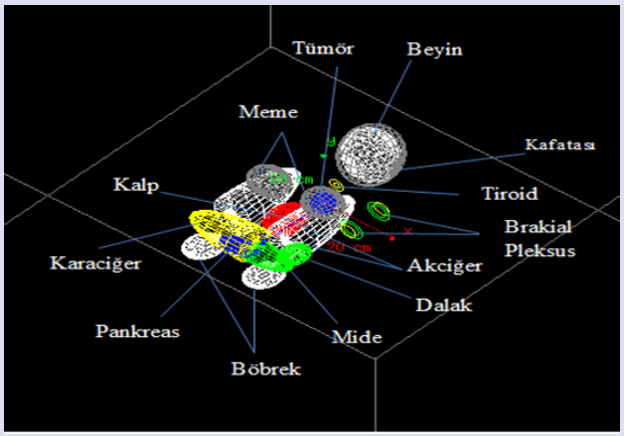


Figure 2. Representation of organs in the phantom prepared in GATE

Dispersed Dose Conversion Coefficient

In the simulation, the source was selected as a proton and photon particle with energy of 250 MeV and irradiation was performed by pencil beam scanning method (PBS). We examined the dose distribution of the tumor and non-target organs that we placed in the left breast as a result of the interactions in the GATE simulation, with the conversion coefficient values. The dose delivered to non-targeted normal organs or tissues is referred to as the “dispersed dose”.

The conversion coefficient was expressed in equation 1:

$$F = \frac{Dd}{Dt} \quad (1)$$

where F was the dispersed dose conversion coefficient, Dd and Dt were the doses delivered to non-targeted tissues and the targeted tissue, respectively. [12] Using table 2 data, the target dose value (Dt) was determined separately for the proton and as the non-target organ(s) dose value (Dd).

Table 1. Conversion coefficient values obtained for tumors and other organs

Proton (F)		Foton (F)	
Left Breast	0.220	Left Breast	0.163
Right Breast	0.008	Right Breast	8.486×10^{-4}
Tumor	1	Tumor	1
Brakial Pleksus	0.001	Brakial Pleksus	2.665×10^{-5}
Skull	2.676×10^{-9}	Skull	1.198×10^{-6}
Brain	1.298×10^{-9}	Brain	4.896×10^{-7}
Thyroid	1.567×10^{-9}	Thyroid	1.678×10^{-6}
Left Lung	7.210×10^{-8}	Left Lung	1.977×10^{-6}
Right Lung	4.459×10^{-9}	Right Lung	6.049×10^{-8}
Liver	4.994×10^{-8}	Liver	5.085×10^{-8}
Left kidney	1.669×10^{-9}	Left kidney	3.105×10^{-8}
Right Kidney	1.034×10^{-9}	Right Kidney	2.567×10^{-8}
Heart	2.189×10^{-7}	Heart	1.908×10^{-5}
Pancreas	8.484×10^{-10}	Pancreas	2.222×10^{-7}
Stomach	7.354×10^{-10}	Stomach	7.083×10^{-8}

Results and Discussion

The global tumor volume placed in the left breast is irradiated by a beam of protons and photons produced by a 300,000 accelerated beam of protons and photons with an energy of 250 MeV. Tumordose actor was called up from determined folder and counted by dose integral account. The pen beam scanning method was used for irradiation with protons and photons. In that study, the hydraulic process was identified in the Physics list, and proton and photon beams were used as a resource. Two separate irradiations were implemented for proton treatment and photon treatment methods. It was observed how many doses a tumor in the left breast received along with how many doses other critical organs were exposed and a comparison was made between the data. Clinically, it is planned to treat a breast tumor with approximately 2 Gy of absorbed radiation per day, 5 days a week, for a period of 5 or 6 weeks, depending on the tumor size. With this planning, it is aimed to irradiate approximately 50 Gy dose to the tumor at the end of the treatment. [7] In Table 1, 15 different organ structures and their stored dose values are given. Dose data in non-field organs remains very low.

Table 2. Dose values of Proton beam and Photon beam stored in organs for DoseActor algorithm of GATE for a single run at 250 MeV.

Proton DoseActor		Foton DoseActor	
Left Breast	2.13663 e-03 Gy	Left Breast	6.966450 e-06 Gy
Right Breast	8.32431 e-05 Gy	Right Breast	3.610050 e-08 Gy
Tumor	9.69002 e-03 Gy	Tumor	4.2541 e-05 Gy
Brakial Pleksus	1.32034 e-05 Gy	Brakial Pleksus	1.134 e-09 Gy
Skull	2.59312 e-11 Gy	Skull	5.09889 e-11 Gy
Brain	1.25811 e-11 Gy	Brain	2.08297 e-11 Gy
Thyroid	1.51849 e-11 Gy	Thyroid	7.138440 e-11 Gy
Left Lung	6.98735 e-10 Gy	Left Lung	8.41123 e-11 Gy
Right Lung	4.32123 e-10 Gy	Right Lung	2.57341 e-12 Gy
Liver	4.8393 e-10 Gy	Liver	2.16321 e-12 Gy
Left kidney	1.61762 e-11 Gy	Left kidney	1.32101 e-12 Gy
Right Kidney	1.00281 e-11 Gy	Right Kidney	1.09213 e-12 Gy
Heart	2.12195 e-09 Gy	Heart	8.12 e-10 Gy
Pancreas	8.2216 e-12 Gy	Pancreas	9.45320 e-12 Gy
Stomach	7.12691 e-12 Gy	Stomach	8.01321 e-12 Gy

Figure 3 and 4 show observed dose absorption values for proton (up) and photon (down) at 2D and 3D plots for left sided breast and tumor tissue respectively.

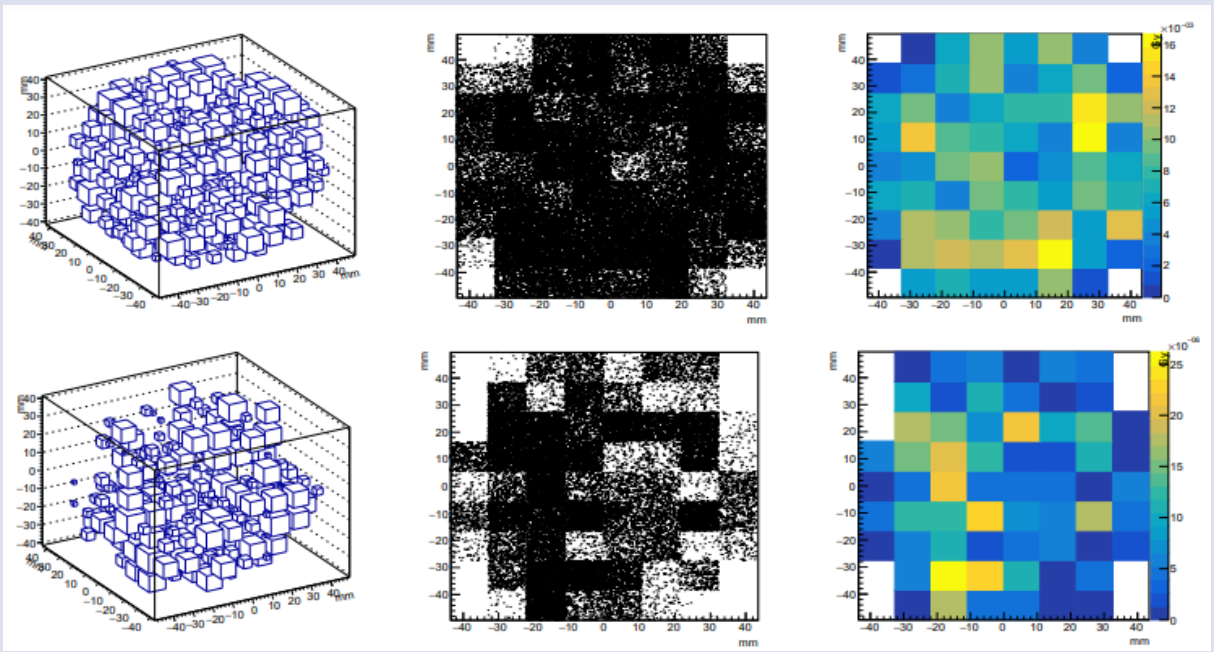


Figure 3. Evaluated via simulation in left breast tissue; first line for proton beams, 3B particle distribution (left), 2B particle distribution (middle) dose distribution (right), second line for photon beams, 3B particle distribution (left), 2B particle distribution (middle), dose distribution (right)

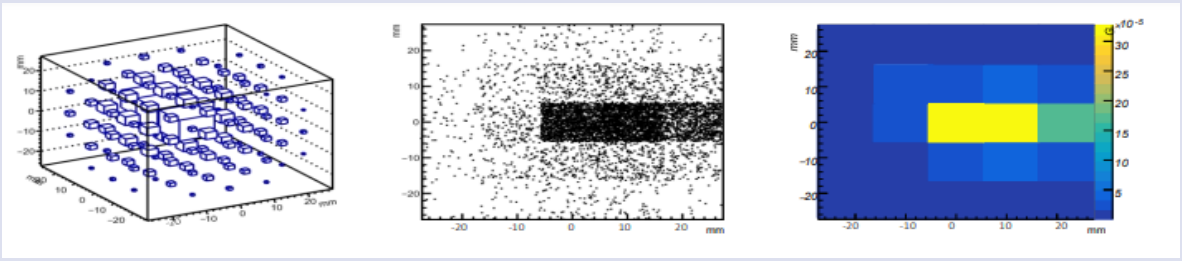


Figure 4. Evaluated via simulation in tumor tissue; first line for proton beams, 3B particle distribution (left), 2B particle distribution (middle) dose distribution (right), second line for photon beams, 3B particle distribution (left), 2B particle distribution (middle), dose distribution (right)

Analyses

The GATE software package was analyzed. The Chi-square method was used for the analysis of the data. In this test, it was examined whether the observed frequencies (Y) were suitable for the expected frequencies (Z) obtained according to a certain hypothesis. The expected values were chosen based on [9] for the proton and photon PTV dose delivery rates as 60% and OAR dose absorption rate as 40%.

The null hypothesis and alternative hypothesis for the chi-square method were established as follows:

H_0: There is no statistically significant difference between proton and photon dose values for tumors and other organs in respect of dose delivery rates.

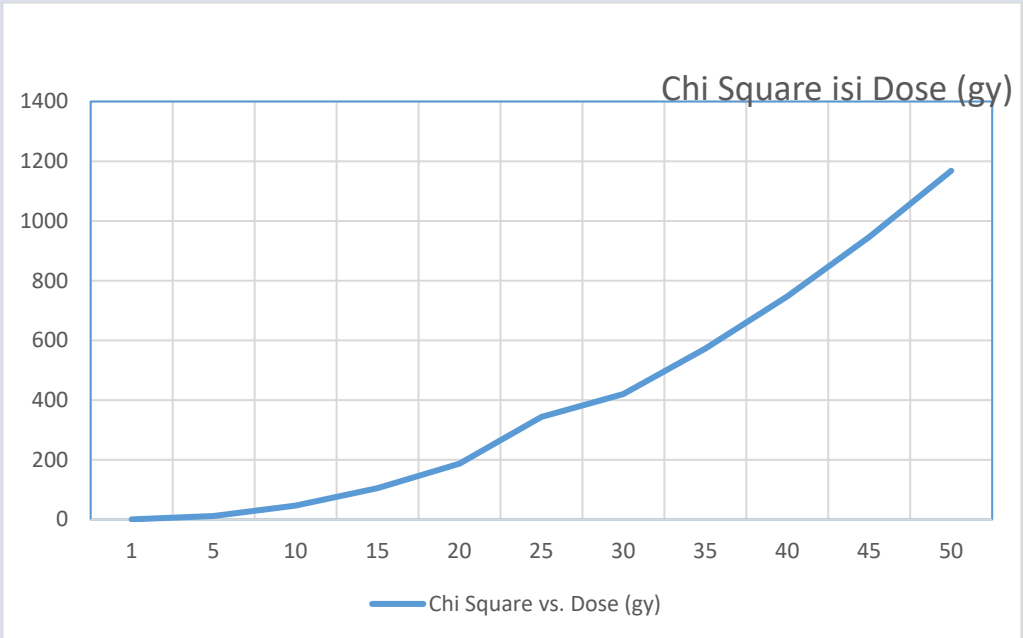
H_1: There is a statistically significant difference between proton and photon dose values for tumors and other organs in respect of dose delivery rates.

The chi-square analyzes of the data we obtained are calculated over the total dose values, and the chi-square values are shown in Table 3. Calculating chi-square values, we have considered 1 Gy normalised dose values of Table-3 since the separation with proton and photon doses has become significant at the order of 1 Gy.

Table 3. Dose Delivery and Dose absorbtion rates where PTV (Primay Tumor Volume) and OAR (Organs At Risk)

Photon Total Dose	% Photon PTV Dose Delivery Rate	Photon Critical Organ (OAR) Total	% Photon OAR Dose Absorption Rate	% Photon Dose Conversion Coefficient (F) for Breast
4.95 e-05 Gy ProtonTotal Dose	85.86 % % Proton PTV Dose Delivery Rate	7.00 e-06 Gy Proton Critical Organ (OAR)Total Dose	14.14 % % Proton OAR Dose Absorption Rate	16.47 % % Proton Dose Conversion Coefficient (F) for Breast
1.19 e-02 Gy	81.27 %	2.23 e-03 Gy	18.73 %	23.05 %

Table 4. Chi-square dose chart



When the percentile values in the dose table are normalized for 1 GL, the test statistic obtained is 0.467, and the Ho hypothesis is rejected because it is greater than the Chi-square table value at the alpha = 0.975 significance level. Statistically significant differences were found between Proton and Photon dose values for tumors and other organs.

Conclusion

In conclusion, the importance of this study is to examine how many doses a tumor receives that we placed in the left breast along with other critical organs that we determined, using the proton radiation treatment and photon radiation treatment methods via the GATE simulation program. [7] There currently have been studies on experimental comparison between proton treatment and photon in the literatüre. [9-12]

The study [9] of Maroufkhani and his friends, MCNPX program Monte Carlo based has been simulated using proton beams. Given to the incoming proton beams in the appropriate energy range causes the Bragg peak to form in the breast tissue. However, due to second particles, the equivalent dose was evaluated for vital organs including the heart and lungs, including photons and neutrons. It has been reported that in breast cancer where proton therapy is compared with photon therapy, the doses formed in the heart and lungs are visible at low rates.

In the study of Lin and his friends [10] ten women patients, early diagnosis of left breast cancer was treated with the help of breast-conserving surgery and radiation. A study was planned by applying all breast proton and photon radiation for a real treatment. Doses given to heart, lad coronary artery, and lungs were made a comparison. Compared to the photon beam plane, proton beam radiation was associated with a 0.2 cm (3) dose to the left anterior descending artery, which is the critical structure for late radiation therapy effects.

In the study of Raptis et al. [11] they investigated the risk of second cancer of critical organs resulting from proton and photon therapy for breast cancer patients. Planning was done with protons and photons to deliver 50 Gy in 25 fractions to the left breast of 12 patients. Lungs, right breast, heart, and esophagus were evaluated as critical organs at risk of developing second cancer. As a result, they stated that protons have more advantages than photons in terms of cancer stimulation.

According to the data we obtained from this study when the percentile values in the dose table are normalized for 1 Gy, the test statistic is 0.467, and the H_0 hypothesis is rejected because it is greater than the Chi-square table value at the alpha = 0.975 significance level. Statistically significant differences were found between Proton and Photon dose values for tumors and other organs if the total dose injected is at the order of 1 Gy or higher. The use of a simulation program (GATE) in this study is promising for similar studies. In radiotherapy, it is important to irradiate the highest radiation energy to the cancerous area, to cause minimal damage to the dose to which other healthy tissues are exposed, and to determine and minimize the out-of-area doses that occur in people working with radiation.

Conflicts of interest

The authors declare that they have no conflict of interest.

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