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Original Article

Feasibility of Flash Radiation Therapy Using X-ray Sources Based on Simulation Method

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Abstract

Background: The main challenge in radiation therapy (RT) has been the destruction of tumor or cancerous tissue while causing the least damage to healthy and normal tissues around the tumor. This is despite the fact that the maximum tolerated dose for normal tissue is limited, and this factor limits tumor destruction with radiation, thus lowering the efficiency of RT. The flash effect was initially proposed as a solution for the movement of the organ under treatment, such as the lung, demonstrating that tissue displacement occurs with breathing.

Methods: In this study, the feasibility of achieving the flash effect, in the direction of the beam and perpendicular to the direction of the radiation beam was investigated using X-rays with energies in keV.

Results: The results of this study, which is the only examination of the effect of distance on radiation, revealed that the amount of energy received in the target increased with the shortening of the distance, and on the other hand, in the direction perpendicular to the radiation, the extent and dispersion of the beam were reduced with the shortening of the distance between the source and the surface of the phantom.

Conclusion: This issue can justify in flash effect, the beam will be more concentrated and the side tissues will be less affected by the radiation compared to conventional radiation therapy

Keywords: Absorbed dose, Radiation therapy, Flash effect, Phantom, X-ray source

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Introduction

Although cancer-related deaths have decreased over time in recent years, cancer is still known as the first and second cause of death of people under 70 years old in different countries, and it is also the most important issue in reducing human life expectancy. Surgery, chemotherapy, and radiation therapy (RT) are the most essential methods of treating cancer and malignant tumors. RT is one of the most important antitumor treatment methods that is widely used all over the world, and 60%-70% of cancer patients with malignant tumors need at least one course of RT during their entire treatment process. In RT, as a result of the interaction of radiation with cancerous tissue, some energy is transferred to it, which can cause the death of tumor cells or stop their growth, leading to improved quality and prolongation of patients' lives (1).

The main challenge in RT has been the destruction of tumor or cancerous tissue with minimal damage to healthy and normal tissues around the tumor, and this is despite the fact that the maximum tolerated dose for normal tissue is limited. This factor limits tumor destruction with radiation, thereby decreasing the efficiency of RT, because even though RT leads to tumor shrinkage, it also leads to toxicity caused by radiation in normal tissues.

In this regard, there have been an increasing number of studies on methods of enhancing the effect of RT on tumor control while simultaneously protecting normal tissues. Among these studies, a study investigated the differential effect of radiation on cancerous and normal mouse tissue at very high dose rates with very short delivery times and with high speed and accuracy (2-5). After receiving promising results from in-vivo dosimetry from the experiments in ultra-high-dose radiation, which is known as the flash effect, due to the significant reduction in the toxicity of normal tissue against conventional RT, this method has gained much attention (6). The flash effect was first introduced as a solution for the movement of the organ under treatment, such as the lung, which occurs with breathing during the treatment. This effect is generally a dose delivery rate of more than 40 Gy per second per pulse to the patient, which is about 10^4 –10^5 times larger than conventional RT in clinical applications. This effect has been reported in preclinical experiments with electrons, kilovoltage x-rays, and proton rays and has become a promising revolutionary method in RT (7-9).

The flash effect can optimize the biological effects of RT. Although the mechanism of the flash effect is still not completely clear, the successful treatment of the first cancer patient with flash RT has made this method a promising technique for clinical applications (6,10,11). The flash effect has been found in preclinical experiments using high-energy X-rays and X-kilovolts, as well as electron beams and protons (12-16), but the use of radiation at very high dose rates produced by accelerators is highly limited. On the other hand, the use of electron beams produced by modified accelerators is only available at a few limited research centers. Therefore, kilovoltage X-ray sources are often used in most pre-clinical research (12,17). In this study, the feasibility of achieving the flash effect only by examining the effect of distance change, which is one of the features of the flash effect, has been evaluated using X-kilo electron volts.

Materials and Methods

Source of Radiation

In this study, two X-ray sources, which are placed in front of each other and produce parallel and opposite rays, were utilized for simulation. These sources were tubes with tungsten anodes, which are capable of continuously producing X-rays with energy in the range of keV. The voltage of the energy spectrum of the produced X-rays varies between 30 keV and 140 keV. The thickness of tungsten is 2 mm, and 1 mm of aluminum was used as a filter.

Phantom

A water phantom with a thickness of 2.5 cm, equivalent to the thickness of a normal mouse, was simulated to investigate and compare the effect of flash with conventional RT. The amount of energy deposited in several spherical dosimetry cells with a radius of 2.5 mm in the direction of radiation and some dosimetry cells placed perpendicular to the radiation was calculated by simulation. The setup utilized for simulation is shown in Figure 1.

Simulation Method

The Monte Carlo calculation technique can be extensively used in the field of radiation. The Monte Carlo particle transfer code is highly useful for obtaining the residual energy in different phantoms from high-energy-focused beams.

In this study, the Monte Carlo N-Particle Transport calculation code was utilized to calculate the remaining energy in the dosimetry cells, and in this code, the source of energetic particle emission is defined by the SDEF card. SDEF parameters, including the coordinates of the center of the source, the geometry of the source, such as flat, point, type of particle, and energy of the source, are employed to define the source.

For a 2.5 cm thick phantom, for two conventional and flash radiotherapy modes, two sources with completely identical characteristics were considered opposite each other on both sides of the phantom, which emit parallel rays in opposite directions toward the phantom. In addition, the only difference between the two radiation modes was the distance between the source and the phantom surface. In each calculation, the total number of particles 2×10^9 was tracked, and the total energy deposited by them was determined in dosimetry cells.

Results

In both simulation methods used in this study, the residual energy was calculated in 5 spherical dosimetry cells with the same geometry and 2.5 mm radius that located in the beam path. The ratio of the deposited energy from the flash mode with respect to the conventional mode in each dosimetry cell was calculated, the details of which are reported in Table 1.

Further, in the direction perpendicular to the radiation beam, in 5 spherical dosimetry cells with the same geometry and a radius of 2.5 mm, the ratio of the deposited energy from the flash mode with respect to the conventional mode in each dosimetry cell was estimated, the results of which are provided in Table 2.

Discussion and Conclusion

In the present study, the feasibility of the flash effect with 140 keV X-ray sources was investigated only by examining the effect of distance on the radiation by simulation and in a phantom with a thickness of 2.5 cm in two directions, namely, in the direction of the radiation beam and in the direction perpendicular to the radiation beam. The residual energy in spherical dosimetry cells with a radius of 2.5 mm was calculated, and the results are presented in Table 1. Based on the results regarding the amount of energy remaining in the direction of radiation, the amount of energy left in the center of the phantom was 0.06% more when the sources were located at a distance of 1 cm from the phantom than when they were at a distance of 18.5 cm, which can increase significantly with the increase in the intensity of the current due to the flash effect.

The findings (Table 2) also demonstrated that in the direction perpendicular to the beam path, the ratio of energy deposited from the flash effect (sources located at a distance of 1 cm) with respect to conventional irradiation (sources located at a distance of 18.5 cm from the phantom surface) decreased compared to the central dosimetry cell by moving away from the center of the phantom. Therefore, the results of this study, which, to the best of our knowledge, is the only examination of the effect of distance on irradiation, revealed that the amount of energy received in the target increased with the shortening of the distance. However, in the direction perpendicular to the radiation, the extent and dispersion of the beam decreased with a decline in the distance between the source and the phantom surface. Accordingly, this issue can justify the protection of healthy tissues due to flash

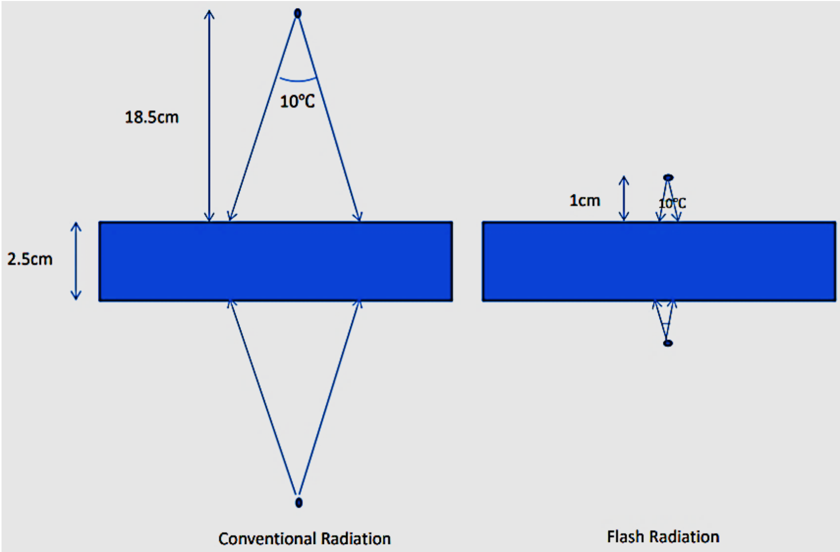

Figure 1. The Simulation Setup for Checking the Possibility of the Radiation Flash Effect

Table 1. Ratio of the Amount of Energy Remaining From the Radiation at a Distance of 1 cm to the Radiation at a Distance of 18 cm in the Direction of Radiation

The Distance of the Dosimetry Cells From the Center of the Phantom in the Direction of Radiation	The Ratio of the Amount of Energy Remaining From Radiation at a Distance of 1 cm to Radiation at a Distance of 18 cm
1 cm	1.08
0.5 cm	1.01
The center of the phantom	1.06
-0.5 cm	1.01
-1 cm	1.08

Table 2. the Ratio of the Amount of Energy Remaining From the Radiation at a Distance of 1 cm to the Radiation at a Distance of 18 cm in the Direction Perpendicular to the Radiation

The Distance of the Dosimetry Cells From the Center of the Phantom in the Direction Perpendicular to the Radiation	The Ratio of the Amount of Energy Remaining From Radiation at a Distance of 1 cm to Radiation at a Distance of 18 cm
2.5 cm	0.94
1 cm	1.01
Center of the phantom	1.06
-1 cm	1.01
-2.5 cm	0.94

compared to conventional RT because the beam will be more concentrated and the side tissues will be less affected by the radiation compared to conventional RT.

Authors' Contribution

Conceptualization: Leila Teimoui, Hosein Khosravi, Rasoul Azmoonfar.
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Methodology: Leila Teimouri, Hosein Khosravi.
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Supervision: Leila Teimouri, Hosein Khosravi.
Validation: Leila Teimouri, Hosein Khosravi.
Visualization: Leila Teimouri, Hosein Khosravi.
Writing–original draft: Leila Teimouri.
Writing–review & editing: Leila Teimouri.

Competing Interests

None declared.

Ethical Approval

This study was approved by Research Ethics Committees of Hamadan University of Medical Scieneces (ethic code: IR.UMSHA.REC.1401.726).

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