Original Article

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Validation of Dosimetric Parameters of Intrabeam Intraoperative Radiotherapy (Iort)

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ABSTRACT

BACKGROUND AND OBJECTIVE: One of the methods for treating breast cancer is radiotherapy using low-kV X-rays in which a dedicated device called INTRABEAM is used along with a few spherical applicators for breast radiation. Due to the single-session nature of this treatment, evaluating the accuracy of the device used for treatment is essential. The aim of this study was to evaluate the dosimetric parameters of the INTRABEAM system with spherical applicators and validate the reported results for clinical use in intraoperative radiotherapy for breast tumors.

METHODS: In this study, dosimetric parameters including percentage depth dose curve (PDD), transfer function (TF) and anisotropy were determined by MCNPX Monte Carlo Simulation Tool and practical dosimetry was done by Gafchromic EBT2 film. The results were quantitatively compared with the results reported by manufacturer of the device (Carl Zeiss) to evaluate the accuracy of the reported data for this treatment system.

FINDINGS: The mean difference when comparing PDD curves was 1.7% and the mean difference between the compared TF values was about 2%. The anisotropy values obtained by Monte Carlo Simulation and Gafchromic EBT2 film were also within the range recommended by the manufacturer.

CONCLUSION: Based on the results, it can be concluded that the dosimetric parameters reported by the manufacturer for spherical applicators of the INTRABEAM system are valid for designing the treatment and radiotherapy for patients.

KEY WORDS: *Breast Cancer, Intraoperative Radiotherapy, Low-Kv X-Rays, Monte Carlo Simulation, Dosimetry.*

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Introduction

Intraoperative radiotherapy in breast cancer includes giving high doses to a patient in one session immediately after surgery (1). One of the most common methods for intraoperative radiation therapy is the use of low-kV X-rays (2). One of the systems currently used for IORT based on low-kV X-rays is the INTRABEAM system, which is done by applying a series of spherical applicators capable of delivering a prescribed dose to the patient in one session (3–5). Considering the importance of this method in the treatment of cancer, Vaidya et al. introduced the IORT technique using low-kV INTRABEAM system and various stages of its implementation in the treatment of breast tumors (3). While introducing the IORT technique using low-kV X-rays by INTRABEAM device, Nairz et al. evaluated the dose distribution obtained by this method and the dose uniformity within the target volume (6).

Armoogum et al. investigated the usability of the INTRABEAM X-ray probe in radiosurgery. The results of this study showed that the X-ray probe has an acceptable performance in this field (7). Avanzo et al. performed in vivo dosimetry in breast cancer IORT using EBT2 film. This study showed that the results of the film dosimetry are fully consistent with the prescribed dosage (8). Sethi et al. investigated the effect of heterogeneity on the dose distribution of the INTRABEAM system using Monte Carlo Simulation, ion dosimetry and film dosimetry. The results showed that heterogeneity causes 6% error in the calculation of soft tissue dose (9). Given that some medical centers in Iran have been equipped with INTRABEAM in recent years (Shohadaye Tajrish Hospital in Tehran, Imam Khomeini Hospital in Tehran and Pasteur Hospital in Mashhad), ensuring the accuracy of the treatment plan provided by this system is highly important.

This issue is a necessity given that the dose is delivered to the patient within one single session and considering the lack of a report on the validity of the dosimetric parameters of INTRABEAM systems in Iran. Therefore, in the present study, the dosimetric parameters for spherical applicators of the INTRABEAM system, which were reported by the manufacturer through ion-chamber dosimeter, were compared with the results of MCNPX Monte Carlo Simulation Tool and film dosimetry to validate the dosimetric parameters of spherical applicators and consequently the accuracy of the treatment plan for patients' radiotherapy by this dedicated device. Due to the favorable spatial resolution, energy independence and tissue equivalence of the Gafchromic films (10–12), the Gafchromic EBT2 film was used for film dosimetry around the applicator and extraction of the relevant dosimetric parameters.

Methods

INTRABEAM device: This study was performed using the INTRABEAM device (Carl Zeiss Company, Germany) located in the department of surgery of Shohadaye Tajrish Hospital in Tehran. The device has a small X-ray source at the end of a 10.0 cm long cylindrical glass tube (diameter of 3.2 mm) (13), which is known as the probe. The accelerated electrons at the end of the probe strike a gold target, and during this process, X-rays and brake radiation are emitted isotropically in all directions. X-ray energy varies from 30 to 50 kV and electron current varies from 5 to 40 µA (14). In this study, 50 kV x-rays in the current of 40 µA were used. The most important applicators used with this system are spherical applicators that have two different parts including a stem and a spherical part. The spherical diameter of these applicators varies from 1.5 to 5 cm with 0.5 mm step size, and the applicators are named accordingly. The dose rate at the surface of these applicators is a function of the diameter of the applicator and decreases with the increase in applicator diameter (5, 15).

Dosimetric Parameters: The dosimetric parameters of this radiation therapy device include central-axis percentage depth-dose (PDD) curves, transfer function for different applicator diameters (1.5 to 5 cm with 0.5 mm step size) as well as the anisotropy of these applicators at a distance of 1 cm from the applicator surface and at different angles relative to the central axis of the applicator (angle of 0 ° to 90 °). PDD can be defined as the percentage of dose changes at different distances from the probe tip along its central axis and according to the following equation (16):

$$PDD=\left(\frac{D_d}{D_s}\right)\times 100 \qquad (1)$$

In this respect, D_s and D_d are the dose values in the vicinity and the distance of D from the probe tip, respectively. The transfer function (TF) can be defined as the dose ratio in the presence of the applicator (probe plus applicator) to the dose in the absence of the applicator (bare probe) at the same depth of D, according to the following equation (16):

$$TF=\left(\frac{D_{probe+Applicator}}{D_{probe}}\right)_d \qquad (2)$$

The anisotropy at distance of r from the surface of the applicator and angle of θ relative to its central axis, $A(r,\theta)$, which can also be defined as follows (16):

$$A(r,\theta)=\frac{[D(r,\theta)-D(r,0)]}{D(r,0)}\times 100 \qquad (3)$$

In this respect, $D(r,\theta)$ is equal to the dose at the distance of r and angle of θ relative to the central axis of the applicator and $D(r,0)$ of the dose at the same distance to the central axis of the applicator. It should be noted that all these parameters were measured and reported through dosimetry in water with Soft X-Ray ionization chambers (TM23342) by the manufacturer and in accordance with the recommendations of the TG-61 protocol (17) for all applicators and bare probes.

Monte Carlo Simulation: The MCNPX Monte Carlo code was used to simulate the INTRABEAM system miniature X-ray source and its spherical applicators (18). The 2D and 3D view of the simulated probe with a 2.5 cm spherical applicator is shown in fig. 1.

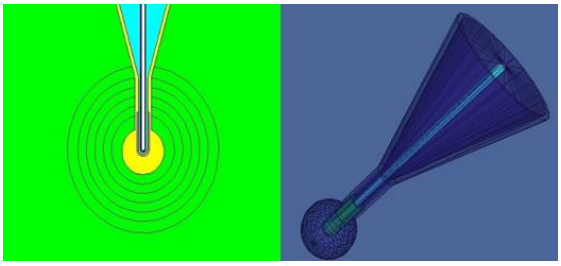

Figure 1. Two-dimensional and three-dimensional view of the X-ray probe and the 2.5 cm applicator simulated by MCNPX code. The space around the applicator is divided into concentric spherical surface to allow the use of geometry splitting with Russian Roulette.

After simulating the INTRABEAM system, all the dosimetric parameters required for bare probe and spherical applicators of different diameters (1.5 to 5 cm) inside a 30 × 30 × 30 cm^3 water phantom were calculated in accordance with equations 1 to 3. It is worth noting that in order to calculate absorbed dose in all cases, the standard *F8 tally was used in spherical cells with a radius of 0.5 mm. Due to the low energy of the X-rays, geometry splitting with Russian Roulette was also used to reduce the statistical error associated with the results for values less than 3%.

Film dosimetry: The used EBT2 films were first calibrated by X-rays of 2.5 cm applicator in water and the dose–response curves of films were extracted based on third-order polynomial fit to the obtained data. Due to the large number of applicators used and the limited number of films available, the film dosimetry was only done for the 2.5 cm applicator. To measure and extract the dosimetric parameters of this applicator, a 19.5 × 10.5 cm^2 Gafchromic EBT2 film was selected and its internal space was cut to fit the applicator. The target applicator was placed inside the cut film, and the top of the film was fastened with adhesive around the applicator stem to prevent the film from being separated from the applicator during the radiation process. The film and applicator sets were then placed in a 30×30×30 cm^3 water phantom, and the film was radiated at a dose of 10 Gy on the applicator surface (Fig 2). Due to the relatively low doses used (maximum of 10 Gy), all radiated films were read in the red channel (19, 20).

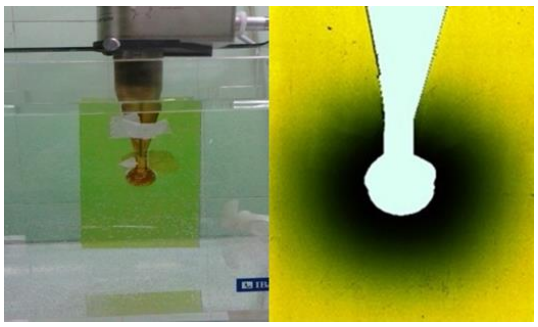

Figure 2. How to place the film around the 2.5 cm applicator to extract dosimetric parameters inside the water phantom (left) and the color changes of the radiated film (right)

Finally, by processing the radiated film by ImageJ software and extracting the film response, PDD, transfer function (TF) as well as anisotropy values were determined according to equations 1 to 3. To determine the anisotropy, the film response was extracted at 1 and 2 cm distances from the surface of the applicator at angles of 0 to 90 degrees relative to the central axis of the applicator. To quantitatively evaluate the agreement in PDD results obtained from the Monte Carlo simulation, film dosimetry and ion dosimetry, we used gamma index analysis with 2% dose difference (DD) and 2 mm distance to agreement (DTA) (21). Relative difference between the results was considered as a criterion for measuring the difference between the obtained TFs. In addition, to evaluate the accuracy of the anisotropy values obtained for different applicators, these values were compared with the range of acceptable variations for this parameter recommended by the manufacturer.

Results

By comparing the results, we can conclude that there is an acceptable agreement between the values reported by the manufacturer and the Monte Carlo simulation, and the mean difference between the compared PDDs was 1.7%. The results of the gamma index analysis also showed that at more than 95% of the investigated depths for all evaluated applicants, the gamma index value was less than one, indicating an acceptable agreement between the results. The PDD curves obtained by Monte Carlo simulation for spherical applicators with different diameters and comparing the results with those reported by the manufacturer are shown in Figures 3 and 4.

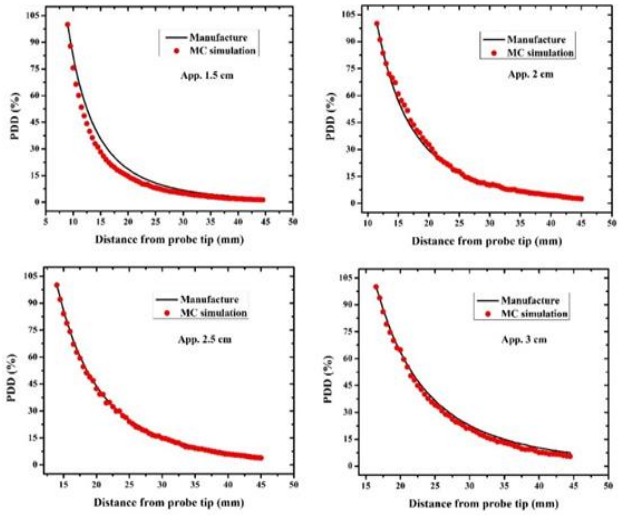

Figure 3. Comparison of PDD curves obtained by Monte Carlo simulation and results reported by the manufacturer for spherical applicators of 1.5 to 3 cm diameter

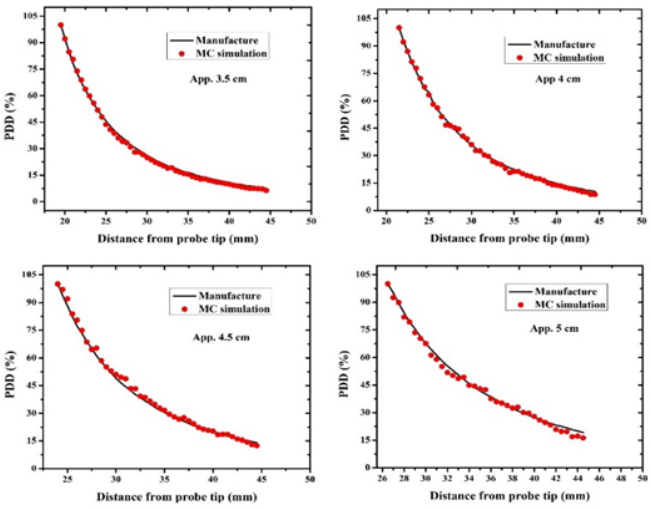

Figure 4. Comparison of the PDD curves obtained by Monte Carlo simulation and the results reported by the manufacturer for spherical applicators of 3.5 to 5 cm diameter

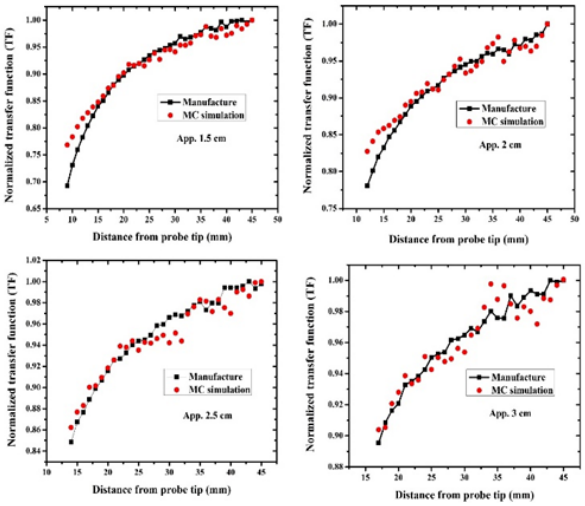

Figure 5. Comparison of the values of the transfer function calculated by Monte Carlo simulation and the results reported by the manufacturer for spherical applicators of 1.5 to 3 cm diameter

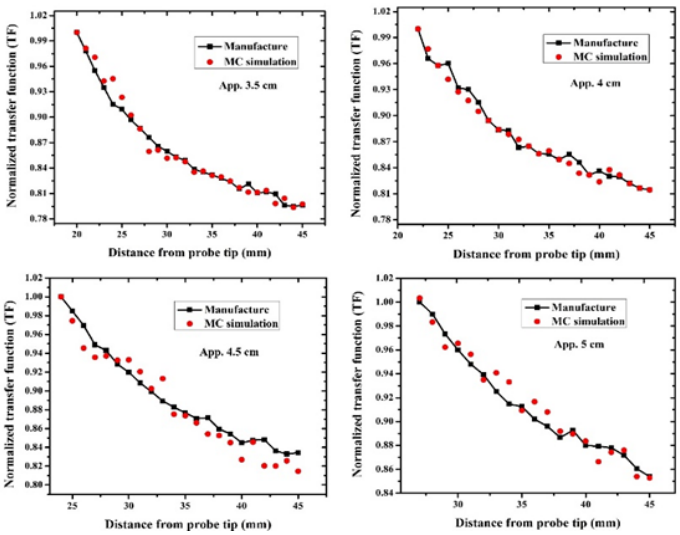

Figure 6. Comparison of the values of the transfer function calculated by Monte Carlo simulation and the results reported by the manufacturer for spherical applicators of 3.5 to 5 cm diameter

As can be seen from the results in figures 5 and 6, there is an acceptable agreement between the results, with the mean difference between the results being about 2%. Only in areas very close to 1.5 cm and 2 cm applicators this difference reaches about 9%, which can be associated with the very high dose gradients in these areas due to the low average energy of the X-ray emission spectrum from these two applicants. The maximum anisotropy for the applicators reaches about 11% for a spherical applicator with a diameter of 4 cm (Fig 7).

The PDD curve of the film dosimetry for the 2.5 cm applicator along the center axis of the applicator and comparison with the results of the manufacturer's Monte Carlo simulation and ion dosimetry is shown in Figure 8. The maximum difference between the PDD measured by EBT2 film and the results of Monte Carlo simulation and the values reported by the manufacturer were 0.2% and 0.3%, respectively. The results of the gamma index analysis also confirmed the agreement between the results and the gamma index value was less than one in almost all depths. The anisotropy values obtained from the film dosimetry of 2.5 cm spherical applicator at distances of 1 and 2 cm from the surface of the applicator are shown in Figure 9. As can be seen in Figure 9, the variation range of anisotropy at 2 cm from the surface of this applicator is more evident than 1 cm from the surface of the applicator.

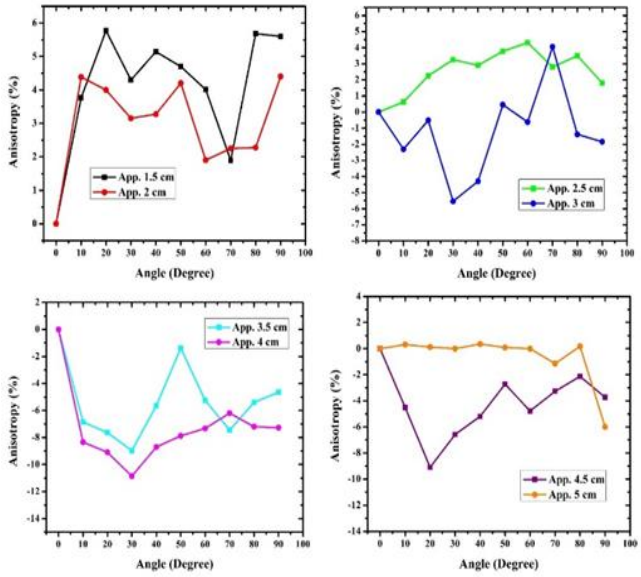

Figure 7. Anisotropic changes with increasing angle to the central axis of the applicator at 1 cm from the surface of different spherical applicators

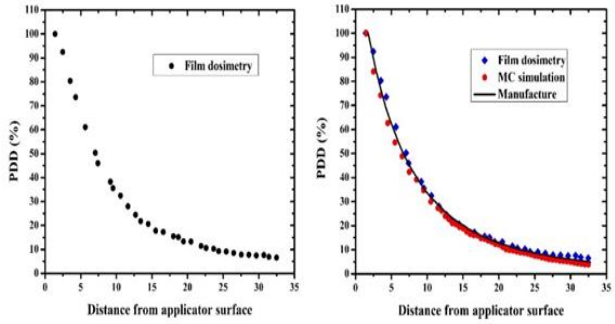

Figure 8. PDD curve of the film dosimetry around the 2.5 cm applicator (left) and comparison of the results with the data obtained by the Monte Carlo simulation and the values reported by the manufacturer (right).

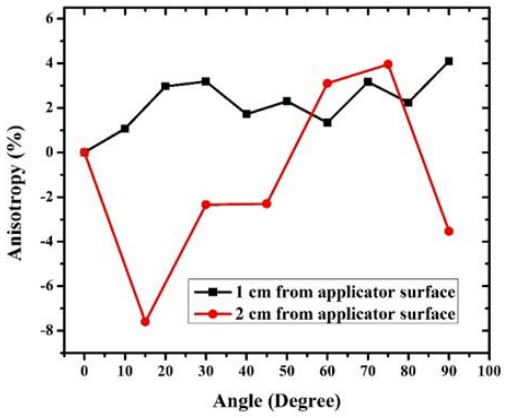

Figure 9. Changes in anisotropy values of the 2.5 cm applicator at 1 cm and 2 cm from the applicator surface

Discussion

The results of this study showed that the dosimetric parameters of spherical applicators reported by Carl Zeiss are valid for clinical use in the treatment of patients with breast cancer. The only similar work on validation of dosimetric data of the INTRABEAM Spherical Applicators system is a study by Xiao et al. in 2015 (22). In this study, the dosimetric properties of spherical applicators were obtained by ion dosimetry inside the water phantom and compared with the results reported by the manufacturer for this treatment system. The results confirmed the accuracy of the reported data for the INTRABEAM system; the maximum difference between the PDD curves was 2% and the maximum difference between the transfer functions and the reported values was about 2%.

The differences obtained for the dosimetric parameters in the present study are also comparable to the results reported by Xiao. With the increase in distance from the probe tip, PDD drops significantly, which is justified by the continuous decrease in the photon flux with the increase in depth and absence of dose accumulation due to the use of low-kV X-rays. The significant differences observed in the 1.5 cm applicator can be attributed to the very high dose gradient of the PDD obtained by this applicator, which is due to the low-energy X-ray spectrum and the uncertainties regarding the placement of ion chamber in water phantom. As shown in the results, for applicators of 1.5 to 3 cm diameter, the transfer function has an increasing behavior with increased depth.

However, for larger diameter applicators, the transfer function has inverse relationship with increased depth. The reason for this difference in the process of transfer function can be attributed to the presence of an aluminum filter in the four small applicators (1.5 to 3

cm) and the absence of this filter in the design of larger spherical applicators (23). According to the reported results, it can be said that the variation range of anisotropy increases with the increase in applicator diameter, which can be attributed to the increase in the number of photon interactions in the spherical part of the applicator and the probability of X-ray scattering at larger angles.

The acceptable variation range of anisotropy values for spherical applicators of different diameters is at 1 cm from the surface of the respective applicator and angular distance of 0 to 90 degrees (16). By comparing the variation range of anisotropy values for the spherical applicators, it can be concluded that the anisotropy values obtained by the Monte Carlo simulation for different applicators often fall within the range of acceptable variations considered for these applicators. Comparison between the results of the film dosimetry and the results reported by the manufacturer as well as the anisotropy values with the variation range reported for the 2.5 cm applicator indicates the fact that the Gafchromic EBT2 film can be used as a reliable and accurate tool for determining the dosimetric parameters of this radiation therapy device.

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