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TECHNICAL NOTE

Evaluation of dose distribution of an intraoperative radiotherapy device using thermoluminescent dosimeters and radiographic films

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ABSTRACT

Background: To investigate dose distribution of the 5cm spherical applicator of the INTRABEAM™ intraoperative radiation therapy (IORT) device via thermoluminescence dosimeters (TLDs) and Radiographic films. Independent dose distribution assessment of IORT devices is considered important. Several methods are described for this purpose, including TLDs and films. However, Radiographic films are not routinely used.

Materials and methods: Twenty TLDs were used for depth dose measuring and evaluating the isotropy in water. Additionally, the isotropy was assessed separately via Radiographic films in air by drawing isodose curves.

Results: TLD measurements showed a steep dose decline which the relative average dose of 0.94 at the applicator surface reduced to 0.32, 0.13, and 0.07 at 1, 2, and 3 cm depths in water, respectively. Some remarkable isodose curves prepared using Radiographic films showed forward anisotropy of the 5 cm applicator.

Conclusion: A very steep dose decline and approximately isotropic dose distribution of the 5 cm applicator were observed via TLD measurements. Radiographic films showed acceptable potential for drawing dose distribution maps. However, they should be applied in more various radiation setups to be implemented more confidently.

Key words: intraoperative radiation therapy; depth dose; isotropy; thermoluminescent dosimetry; radiographic film

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Introduction

Intraoperative cancer treatment via various intraoperative radiation therapy (IORT) machines has gained significant attention over the last decade. The relative ease of use, patient convenience, time preservation, and acceptable clinical outcomes are considered certain reasons [1].

The importance of assuring the quality of the radiotherapy machines is obvious for implementing proper treatment procedures [2–4]. The same approach is valuable for IORT machines as well. Even more attention is required to ensure quality assurance of IORT machines owing to the limited clinical experiences in using them [5].

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In this paper, we aimed to independently check the dose distribution of the 5 cm spherical applicator of the low energy 50 keV INTRABEAM™ (Carl Zeiss Surgical, Oberkochen, Germany) IORT device via Percent depth dose and beam isotropy evaluation using thermoluminescent dosimeters and Radiographic films, respectively.

The device is mostly used for breast cancer treatment using spherical applicators of eight sizes, ranging between 1.5 to 5 cm diameter [5, 6]. The X ray generator of the device consists of a thin 10 cm probe, which irradiates X rays in an approximately isotropic manner [6, 7].

Since the implemented methods needed to be checked, only the 5 cm spherical applicator was assessed.

Practically, TLD cubes and Radiographic films are considered different for dose measurement. The former could be applied in many dose measuring approaches, including personal dosimetry, quality assurance, and in vivo dosimetry. In contrast, the latter should be applied more cautiously due to the discrepancies, especially in low energy beam dosimetry which are basically result of some variables including dose rate, beam spectrum variations and beam directions, making radiographic films not routinely usable for such purposes [2, 8–14].

Film dosimetry as a high spatial resolution method is an accepted approach for two dimensional (2D) dose distribution maps, particularly for complex radiation fields, including intensity modulated radiation and high gradient dose distributions. However, this method has limitations, such as energy and dose rate dependence and scanning limitations [15–17]. The limitations are more serious for Radiographic films as they are considered to have fewer dose measurement applications.

Low energy dose measurement approaches are slightly more challenging with significant uncertainties than high energy beam dosimetry; thus, Radiographic films are not applied in such fields [8, 12]. However, the distinction between a precise dose measuring and providing a 2D dose distribution map can be determinative. In other words, Radiographic films are not commonly applicable for absolute dose measuring; although, they could be applied to obtain dose distribution maps, as mentioned in some studies [8], which are mostly concerned with megavoltage energy beams.

Materials and methods

Thermoluminescent dosimetry

Twenty TLDs of a cubic lithium fluoride doped with titanium (LiF: Mg, Ti), resembling TLD-100, with 3.2 × 3.2 × 0.9 mm^3 dimensions was used to assess the percentage depth dose. TLDs were placed in five directions around the applicator, including ±X, ±Y, and the Z axes. The directions are used in all measurements for the machine, which results from the applicator design. ±X and ±Y are the directions of the applicator's lateral plane perpendicular to the probe axis, and the probe axis represents the Z direction.

Four TLDs were placed in each of the five directions from the applicator surface up to 3 cm depth in water, with 1 cm increments. TLDs were sealed in water equivalent plastic envelopes to prevent them from being damaged in water. After submerging the whole setup in the water phantom, a 2 Gy dose was prescribed at the applicator surface, and all the twenty TLDs were irradiated simultaneously, which were shadowed by each other in any direction. Before the radiation, TLDs were annealed for one h in a 400°C oven, cooled down at room temperature for 10 minutes, following by two-hour annealing in a 100°C oven. After the radiation, TLDs were individually read with a Harshaw™ 3500 Reader (Harshaw Chemical Company, Solon, OH) to get each dosimeter's electronic response and convert the signal to the absorbed dose.

Prior to this project, the system had been calibrated according to the periodic quality assurance schedule of our center using a parallel plane Ion Chamber (IC) dosimeter (type PTW 23342) recommended for low energy dose measurement in a specified Zeiss water phantom [5]. In this process, the depth dose was merely measured along the Z axis of the applicator to confirm the correctness of the calculations.

Radiographic film assessment

A Radiographic film type (Kodak X-omat V) was used for visual isotropy estimation of the 5 cm spherical INTRABEAM™ applicator in air. Several radiations were carried out on some 18 × 24 cm^2 films, where the applicator and the probe (Z axis) were perpendicular or parallel to the film pieces to access isodose curves in different probe directions relative to the film surface. The films were not placed

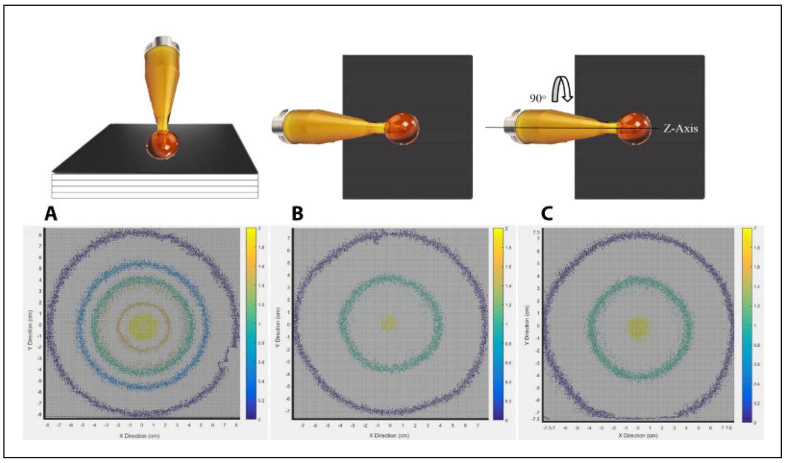

Figure 1. Schematic view of Isodose curves of the 5 cm INTRABEAM™ applicator with corresponding radiation setup. **A.** The applicator and the probe inside it, placed perpendicularly to the center of an 18 × 24 cm^2 Radiographic film; **B.** Applicator and the probe parallel to the Radiographic film piece, which the ±X axis is parallel to the film surface; **C.** Similar to (**B**), with 90° rotation around the Z-axis, the ±Y axis was parallel to the film surface. The setup was carried out in the air with 6 seconds of radiation for each step

in cassettes to avoid electron scattering on the film and merely get the photon distribution map on each film piece [8]; therefore, the film pieces were individually placed in some dark plastic envelopes.

Three radiations on Radiographic films were performed as follows. Firstly, the applicator was placed perpendicular to the film center. The two other steps were performed with the applicator parallel to the film pieces, including the ±X and ±Y axes parallel to the film pieces, for 6 seconds of radiation. Four 1cm thick slab phantoms were placed under the films to provide scatter radiation [8] for each radiation step. Figure 1 represents a schematic view of the radiation setup with the isodose curves provided below. Following the completion of the radiations and processing of the film pieces, the Radiographic films were scanned using a 1000XL Microtek™ flatbed scanner (ScanMaker 1000XL Pro: Microtek International Inc., Hsinchu, Taiwan) with the transmission, positive film modes with 48-bit RGB, and a resolution of 72 dpi with all image modifications on the scanner software turned off. The scanned films were saved in the TIFF (tagged image file format) format and analyzed using Matlab (2016a) to provide the isodose curves for the 5 cm applicator.

Results

Thermoluminescent dosimetry of the 5 cm applicator showed a reducing trend of relative doses up to the depth of 3 cm in water. Figure 2 represents

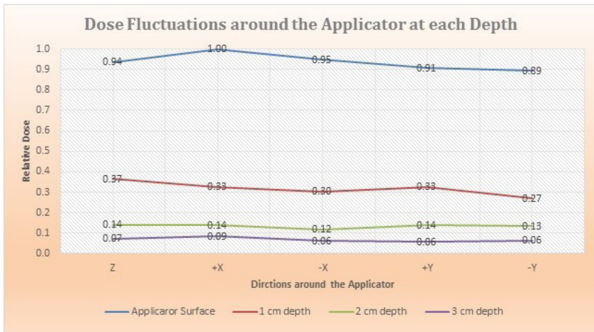

Figure 2. Dose fluctuations of the 5 cm INTRABEAM™ applicator at each depth. The curves are provided using thermoluminescence dosimeters (TLD) measurements in the water phantom. The highest value is normalized to one

the relative dose fluctuation curves of the 5 cm applicator at each depth. As seen, the dose falls rapidly at the 3 cm mark. The average relative surface dose of 0.94 decreased to 0.32, 0.13, and 0.07 at the depths of 1, 2, and 3 cm, respectively. Each value mentioned is the mean of the five relative doses of all directions at any given depth. Also, the relative dose reduction on the Z axis is shown in Figure 3 based on TLD and TPS measurements. Here, the TPS values come from the IC depth dose measurement on the Z-axis, in which the values are normalized to the maximum surface dose for each method. However, it should be considered that the TLD calibration was performed against the same IC, which is mostly recommended for low energy beam dosimetry [5].

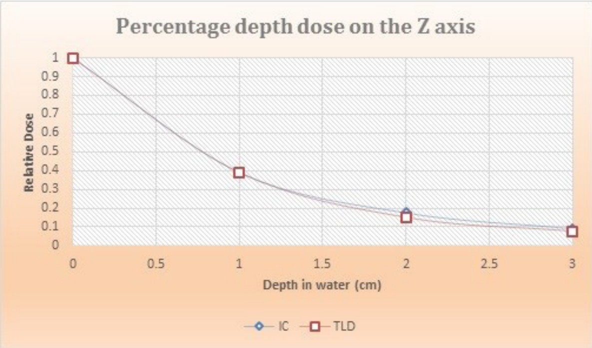

Figure 3. Percentage depth dose on the Z axis. Curves provided using the ion chamber (PTW 23342) and thermoluminescent dosimeters in the water phantom. The Ionization Chamber (IC) values represent the Treatment Planning System (TPS) data set

Figure 1 shows the radiation set up of the Radiographic films with the corresponding isodose curves of each applicator position on film pieces, as mentioned. The dose map on Figure 1A corresponding to the applicator perpendicular to the film represents growing circles of the isodose curves extend between –8 cm to +8 cm in both directions, while it is extended between –7 cm to +7 cm in Figures 1B and 1C, where the Z axis is parallel to the film pieces. A color bar is also seen on the right side of each isodose curve, which is normalized to 2 as the maximum relative dose at the center of each film piece, where the applicator surface touches the film center, corresponding to the yellow spot on the checkerboard of the isodose curve. By enlarging the isodose curves' circles, the relative dose is reduced from the center's maximum dose to lower doses.

Discussion

This paper was mainly aimed to implement an independent INTRABEAM™ quality check to investigate the depth dose and isotropy of the 5 cm applicator using TLD and radiographic films, respectively. Since the two implemented methods were not completely pertinent, they could not be compared with each other as well.

Depth dose curves provided via TLD cubes present a steep dose fall in water, which is mostly considered an advantage of the INTRABEAM™ for protecting healthy surrounding tissues [2, 5, 6, 9]. The dose reduction gradient is reduced with increasing depth. According to Figures 2 and 3, the main dose decline is observed in the first centimeter depth in water, which accounts for ~60% dose drop. Also, IC and TLDs' dose decline trends in Figure 3 are well consistent up to 3 cm depth along the Z direction.

Based on the dose fluctuation curves of TLD measurements shown at each depth, the isotropy can also be evaluated in Figure 2. However, this section's isotropy evaluation does not necessarily reflect the Radiographic film results, as will be discussed later.

In this survey the isotropy of the low energy (50 keV) INTRABEAM™ machine was visually evaluated using Radiographic films. As shown in Figure 1, isodose curves, like some enlarging circles, exhibit similar trends among various positions of the applicator on the Radiographic films in all three isodose curves. The first isodose curve (Fig. 1A) associated with the applicator's perpendicular position is shown to be approximately extended between –8 and +8 cm in both directions of the dose map. In comparison, the next two curves (Fig. 1B and 1C) are approximately extended between -7 and +7 cm. Thus, the dose distribution map seems denser and a bit wider along the Z direction than the lateral planes, which results from a different dose distribution along the Z axis with a higher beam penetration than the applicator's lateral plane. Additionally, the yellow spot centered in the 1st isodose curve (Fig. 1A) seems wider than those in the next two isodose curves. This forward anisotropy resembles some previous studies conducted using different methods, indicating a higher dose in the forward direction of large (4.5 and 5 cm) spherical INTRABEAM™ applicators relative to the lateral plane [9, 18]. Eaton et al. 2013 observed an approximately 10% lower dose in the lateral plane of the 5 cm applicator. On this basis, regarding the 20 Gy dose prescription for breast cancer therapeutic purposes, the mentioned anisotropy results in almost 2 Gy lower dose in the lateral plane of the 5 cm applicator, which is considered clinically insignificant [9]. However, the TLD application in our study did not verify the forward anisotropy, as mentioned earlier. The rationale behind this could be the higher sensitivity of radiographic films than TLD cubes [19]. Additionally, some dose discrepancies due to significant dimensions of $3.2 \times 3.2 \times 0.9$ mm^3 of TLDs in such a high dose gradient field and the TLDs being shadowed by each other during the radiation can be considered as the reason for the disagreement.

Despite all discrepancies via Radiographic film measurements, they could be implemented for getting a better perception of the dose distribution of such treatment machines. A better understanding of the dose distribution via Radiographic films could make them more applicable in such areas of dose assessment. Additionally, owing to their ease of use, lower cost, and fast response compared to self-developed radiochromic films, they seem appropriate to be implemented in such assessments. However, they are not an alternative for radiochromic films, especially for high dose evaluations [20, 21].

Conclusions

Depth dose assessment of the INTRABEAM™ was finely performed via TLDs which showed high gradient dose distribution, indicating that the process should be performed cautiously in order to get a precise dose response.

Visual isotropy assessment of the machine via radiographic films showed reasonable patterns of dose distribution maps indicating that radiographic films have the potential to be finely implemented in further research to be assessed more accurately in different setups and various approaches to dose measurement in order to be applied more confidently.

Conflict of interest

The authors of this paper declare that they have no conflict of interest between them.

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Ethical approval

Ethical approval was not necessary for the preparation of this article.

Informed consent

This article does not contain any studies with human participants or animals performed by any authors.

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