ORIGINAL ARTICLE

Comparison of Rectal Dose in Different Techniques of Prostate Cancer External-Beam Radiotherapy Based on TLD and XR Type T GAFCHROMIC® Film Dosimetry

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Abstract

Background: Radiotherapy of prostate carcinoma often results in high doses to surrounding structures, such as the rectum and bladder. Therefore, these organs should be closely monitored. The aim of this study is to evaluate the dose received by the target volume and rectum to compare two different methods of dose measurement with each other and to check the homogeneity of dose in the tumor volume.

Methods: The dose distribution throughout a planned target volume and the rectum (OaR) in a phantom exposed to 9 MV photon beam, similar to treatment conditions were studied. Several techniques of external beam radiation therapy such as two-, three- and four-field have been planned. Dosimetry was performed using GAFCHROMIC® film and TLD-100 chips.

Results: The rectal and cancer volume measured doses in treatment were similar to the prescribed doses. The results of two dosimetry types were compared with each other as well as with treatment planning. Rectal dose in three- and four-field (equal tumor dose and equal applied dose) techniques were respectively 23.15, 28.87 and 15.22% lower than the tumor dose.

Conclusion: There was not a statistically significant difference between received and prescribed doses. So, this study showed that the Gafchromic film dosimetry can be used for fast dosimetric evaluations.

Keywords: Rectal dose; Radiation therapy; TLD, XR type T film; Prostate cancer

Introduction

Prostate cancer occurs when the cells of the prostate mutate and begin to multiply out of control. These cells may spread (metastasize) from the prostate to other parts of the body, especially the bones and lymph nodes. It develops most frequently in men over fifty.[1,2]

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Radiotherapy of prostate carcinoma often results in high doses to surrounding structures, such as the rectum and bladder. Therefore, these organs should be closely monitored. The late complications manifesting on these organs as a result of radiotherapy can lower the therapeutic ratio and significantly decrease the patient's quality of life.[3] The most important treatment related factors that could lead to creation of late complications on the rectum include total dose to the rectum and the volume of irradiated rectum. Of those, particularly important is the dose delivered to the rectum.[4] Researchers are trying to develop new

treatment techniques, thereby increasing patients' survival and concomitantly minimizing morbidity. Apart from the accuracy of the dose at the point concerned, a uniform dose distribution within the target volume is also crucial for successful radiotherapy.

It is generally accepted that variance in the dose delivered to the patient should not be greater than 5% at the reference point.[5] More recently, a tolerance of 3.5% has been suggested.[6] Subsequently, the International Commission on Radiation Units and Measurements (ICRU) report No. 50 has recommended dose homogeneity of between -5% and +7% of the prescribed dose throughout the planned target volume (PTV).[7] Furthermore, treatment planning for prostate cancer is complex because of the close vicinity to the vital organs, i.e. the rectum and bladder.

This study first aimed to compare two different dosimetry methods (TLD and XR type T film) and also to correlate treatment techniques with the risk of rectal sequelae in patients with prostate cancer treated by external beam radiotherapy. Due to the development of radiochromic films, they have become significant dosimetry tools in diagnostic and therapeutic radiology.[8-10] In recent times, films which are optimized for lower energy x-ray analysis[11-15] have been studied.

Materials and Methods

A. Alderson Rando Phantom

This work was carried out at the radiotherapy center of Imam Reza Hospital in Mashhad, Iran. An Alderson Rando phantom was used instead of real patients. The Rando phantom is an anthropomorphic phantom consisting of a human skeleton embedded in the synthetic tissue-equivalent material forming the natural body contours. It had no limbs and was cut into 36 sequential numbered slices. Each slice contains a regular matrix of 5 mm diameter holes, 2.5 cm apart. The holes were normally filled with plugs of the same material, which could be removed and replaced by TLDs for dose measurement at selected locations.

B. Radiochromic film

XR type T model GAFCHROMIC® film was used in our experiments. These films were originally designed for industrial applications by International Specialty Products (ISP), Inc. (Wayne, NJ, USA). In radiochromic films, an organic-based dye was used, which changed color due to polymerization when exposed to radiation. The color of XR type T films turned from orange to brownish-black, depending on the level of exposure.[16] The active layer of the film was sandwiched between two sheets of yellow, transparent polyester, having a thickness of 97 µm and a density of 1.38 g/cm.^{3} The active layer was about 28 microns thick with a physical density of 1.75 g/cm.^{3} This means that the effective depth of measurement, scaled by density, was 0.016 g/cm^2 for the XR type T GAFCHROMIC® film.[17]

C. Radiochromic film dosimetry

To measure the film net optical density (OD), the Nuclear Associates Radiochromic Densitometer, Victoreen, Model 07-443 was usec that was especially suited to make spot measurements on GAFCHROMIC® dosimetry film, since it employed an optimum red LED light source and a filter to measure in a narrow band centered at about 670 nm. The physical aperture of the densitometer was 2 mm. This film was handled in accordance with the precautions recommended in TG-55 (Niroomand-Rad *et al* 1998).[18] For calibration, the net OD was measured for doses ranging from 5–15 Gy. Measurements were performed by irradiating 5 pieces of film (2×3 cm^2 in size) with 9 MV photon beams from a Nepton 10-PC linear accelerator. The pieces of film were placed around the central axis of the beam, in the plane at the depth of 10 cm in a 30×30 cm^2 Perspex plates. A 10×10 cm^2 field size at a 100 cm source–surface distance (SSD) was used for irradiations. Sufficient amounts of plates (12 cm), placed below the film pieces, were used to provide full backscatter. The optical densities of the film pieces were measured 24 hours after irradiation. Each piece of unexposed film was measured before irradiation to obtain the background signal for subtraction from the after exposure optical density in order to obtain the net optical density. The film was removed from its light tight envelope only during irradiation and readout to reduce the effects of the ambient light.[19] A control set of films, not exposed to radiation, was used to monitor any change in the film OD due to the temperature or ambient light.[20] The doses were delivered based on the calibrated linac output, measured in accordance with the TG-51 protocol.[21] The output measured before and after irradiation, did not vary by more than 0.2% for the beam quality used in this study.

D. Thermo-luminescent dosimeters (TLDs)

1×3×3 mm LiF:Mg:Ti TLD chips (TLD-100, Bicron NE, Solon OH) were chosen as radiation detector. When using TLDs, vacuum tweezers should

always be used. Mechanical tweezers and fingers should not be used. The features of TLDs were simulate "point detector" in medical physics applications, reusable hundreds of times, long term response retention, nearly tissue-equivalent, ±15% sample-to-sample uniformity, and repeatability of within 2% or better.[22]

For calibrating TLD-100 chips, it was suggested that they be exposed to doses similar to those expected to measure in research. For annealing procedures, TLDs were heated up to 400 °C for 1 hr followed immediately by 100 °C for 2 hr and then cooled to room temperature. Exposed TLDs were read in a Harshaw model 3500 (Harshaw, OH)[23] TLD reader.

E. Experimental set-up

Four techniques were compared including a) Two-field (AP-PA): the advantages of the parallel opposed field were the simplicity and reproducibility of the set-up, homogeneous dose to the tumor, and less of geometrical miss (compared with angled beams), given that the field size was large enough to provide adequate lateral coverage of the tumor volume. A disadvantage was the excessive dose to normal tissues and critical organs above and below the tumor; b) Three-field arrangement: anterior and opposing lateral fields give a rectangular distribution which ensured treatment of the external iliac nodes lying at the anterior position and internal iliac nodes situated in the posterior position. This technique reduced the dose to the posterior rectal wall; c) Four-field arrangement: in fact, the dose to the peripheral tissues could be higher than the midline dose in AP-PA. Reduction of the dose to subcutaneous tissue and normal tissue surrounding the tumor could be achieved by using a combination of more fields. When the primary tumor was large or involved seminal vesicle, a four-field technique was preferred to increase the dose to the posterior volume. In this study, two plans of four-field technique were used. The first method uses equal applied dose while the second one used equal tumor dose.[24,25]

F. Dose calculations

Alderson Rando phantom (reference man) was used as a patient for determining the received dose. Treatment fields were simulated, using a simulator (Simax, Poland) and planned, using a TPS (Alfard, Poland). A 9 MV beam from a Nepton 10-PC linear accelerator was used in this study.

The dosimetry result based on treatment planning, TLD and Gafchromic film (XR type T) measurements were compared with each other. The rectal and cancer volume dose (PTV) were evaluated by placing thermo-luminescence dosimeter (TLD) at each marked location inside the phantom. The films were also exposed after being tightly packed in between phantom slices, parallel to the central axis of the beam in exactly the same position and geometrical arrangement as the TLDs. Relative dose distribution, using the films, was also compared with TLD results. The results were analyzed, using SPSS (Statistical Package for Social Science) software. To determine the best technique, statistical analysis was preformed, using One-Way ANOVA and LSD test.

Alderson Rando phantom was placed under the linear accelerator in a straight position. Four chosen techniques (AP-PA, three-field, four-field with equal tumor dose and four-field with equal applied dose) were used. Five points were selected on the slice for dosimetry. A, B, C and D illustrated points chosen in tumor volume and R showed the rectum. The experiments were repeated 3 times and the results shown were the average of the 3 data sets. Figure 1 is a schematic diagram indicating the positions of the chosen points; A, B, C, D and R.

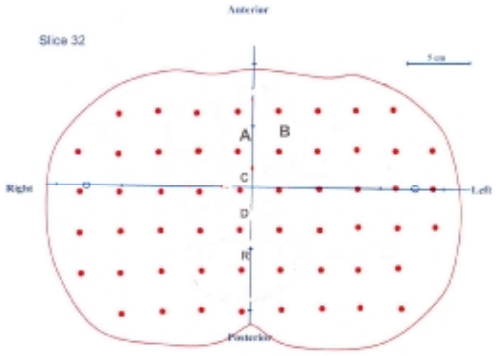

Fig 1: The positions of the points A, B, C, D and R for dosimetry.

Statistical analysis of the rectum and cancer volume (prostate) data was done by Independent T-Test and the comparison of TLD and Gafchromic film dosimetry with treatment planning dose was done by paired t-test (SPSS Inc.).

Results

The fraction of the rectum receiving a dose by TLD in treating prostate cancer was as follows: two-field; 2.09±0.18 Gy, three-field; 1.52±0.20 Gy, box with

equal applied dose; 1.66±0.00 Gy and box with equal tumor dose; 1.41±0.34 Gy. The mean receiving dose by TLD to the prostate was as follows: two-field; 2.03±0.05 Gy, three-field; 1.974±0.036 Gy, box with equal applied dose; 1.96±0.02 Gy and box with equal tumor dose; 1.98±0.10 Gy. Figure 2 shows the comparison of the mean measured dose by TLD in all of the techniques following prostate cancer treatment. Technique no. 1 indicates two-field, technique no. 2 demonstrates three-field, technique no. 3 shows four-field with equal tumor dose, and technique no. 4 indicates a box with equal applied dose.

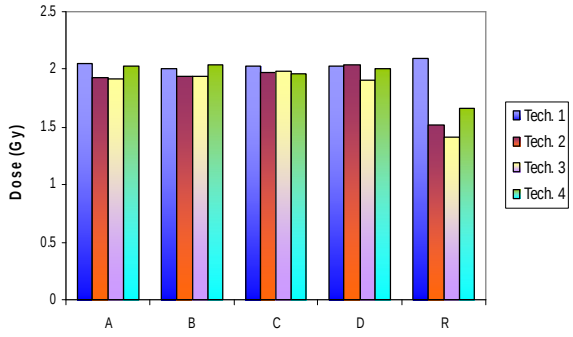

Fig 2: Comparison of the mean measured dose by TLD following prostate cancer treatment.

Except two field technique (AP-PA), *P* value for all other techniques was lower than 0.05. Statistical results are as below: two-field; *P*=0.483, three-field; *P*=0.017, box with equal tumor dose; *P*=0.049, and box with equal applied dose; *P*=0.001.

The rectal volume received dose by film in treating prostate cancer was as follows: two-field; 2.13±0.14 Gy, three-field; 1.79±0.08 Gy, box with equal applied dose; 1.64±0.09 Gy and box with equal tumor dose; 1.79±0.05 Gy. The mean measured dose by film to the prostate was as follows: two-field; 2.00±0.15 Gy, three-field; 2.07±0.05 Gy, box with equal applied dose; 2.07±0.04 Gy and box with equal tumor dose; 2.07±0.14 Gy. The comparison of the mean measured dose by film in the rectum and cancer volume among the techniques is shown in Figure 3.

Analysis of the target volume data showed that there were no significant differences throughout it. Statistical analysis in this case was also done using independent t-test. In the comparison of all points data, *P* value is lower than 0.001.

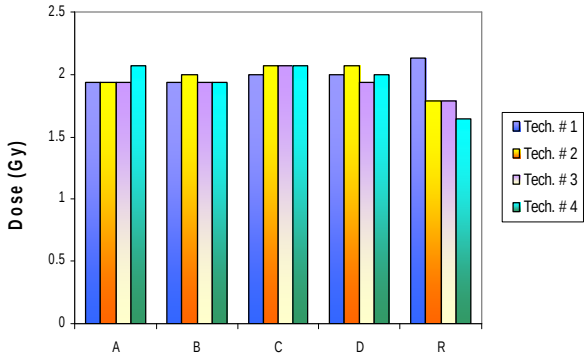

Fig 3: Comparison of the mean measured dose by film following prostate cancer treatment.

The comparison of TLD and Gafchromic film dosimetry with treatment planning dose was done by paired t-test. The measured dose (with TLD and Film) in all the points was significantly the same as the prescribed dose by treatment planning. Statistical results are as below: two-field; *P* (prostate)=0.407, *P* (rectum)=0.687, three-field; *P* (prostate)=0.333, *P* (rectum)=0.133, box with equal tumor dose; *P* (prostate)=0.768, *P* (rectum)=0.639, and box with equal applied dose; *P* (prostate)=0.081, *P* (rectum)=0.709.

Figure 4 represents a comparison of the two dosimetric methods with treatment planning in three-field technique four which was exposed to 2 Gy absorbed dose in a Rando phantom. The comparison of the results by TLD, film and treatment planning in four-field technique with equal tumor dose is shown in Figure 5.

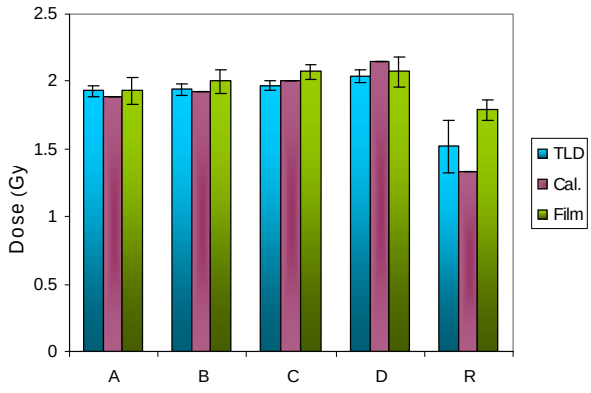

Fig 4: Comparison of the mean measured dose by TLD and film with planned dose in three-field technique exposed by 9 MV linear accelerator.

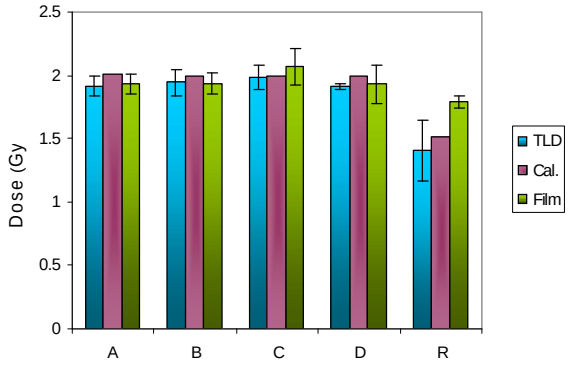

Fig 5: Comparison of the mean measured dose by TLD and film with planned dose in four-field technique with equal tumor dose exposed by 9 MV linear accelerator.

Discussion

In the comparison of the TLD and XR type T film dosimetry resulted with the prescribed dose (Figure 4), it was demonstrated that there was not a statistically significant difference between the measured and prescribed dose in the tumor volume and rectum. Also, the two dosimetry methods data confirm each other. So, films could be a faster way than TLDs for evaluating the accuracy of treatment planning. The use of TLD and Gafchromic film to assure submillimeter accuracy for image-guided radiosurgery was done in 2008 by Ho et al.[26]

Moreover, this study showed that dosimetry using TLD and film during radiotherapy could have a significant role as a predictor of the best technique for preventing future rectal complications. Based on the obtained results, there is a uniform dose distribution throughout the tumor volume. For AP-PA technique, the mean rectal dose is higher than the target volume dose. Thus, by using multiple fields, the ratio of the tumor dose to the normal tissue dose is increased. Although multiple fields can provide good distribution, there are some clinical and technical limitations to these methods. For example, certain beam angles are prohibited because of presence of critical organs. Also, the set-up accuracy of a treatment may be better with parallel rather than with multiple angles beam arrangement. In this research, it is demonstrated that, considering similar target volume, best normal tissue sparing is obtained by using the four-field with equal tumor dose and three-field techniques. In 2004, Milecki et al. conducted a similar study with the title of the comparison of radiotherapy techniques for treatment of the prostate cancer: the three-field vs. the four-field.[27] The results by TLD, film and treatment planning in four-field technique with equal tumor dose were shown in Figure 5.

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