Chapter 254

Dose profile evaluation for two fields of a 6 MV LINAC X-ray beam

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ABSTRACT

Radiotherapy is an established method of cancer treatment and is widely applied to control this disease. Medical Linear Accelerators (LINAC) is widely used in modern radiotherapy due to their flexibility and high therapeutic reliability. Traditionally, national and international codes of conduct provide guidelines on dosimetry with a reference field of 10x10 cm², considering that for larger fields, dosimetric parameters are well-defined and can be accurately measured. In this work, a LINAC X-ray beam of 6 MV was used to irradiate a solid water phantom, using fields of 10x10 and 5x5 cm². X-ray beam was generated in a 6MV linear accelerator (Linac) model Synergy Platform from the manufacturer Elektra. Radiochromic film sheets were used to record dose profiles inside the solid water phantom. For irradiation of the phantom loaded with the film, it was positioned twice 1.0 m away from the focus of the X-ray beam for both field sizes. In the first irradiation, the phantom was exposed laterally to obtain the longitudinal dose variation profile and in the second irradiation, the phantom was irradiated frontally. The longitudinal profile of the absorbed dose obtained showed the maximum dose value at 1.30 cm depth for both fields. Axial dose profiles were recorded at 1 cm depth and showed a plateau in the axis Y for both fields. The plateau for the field of 10x10 cm² in axis X presented a depression in the central area and that did not happen in the 5x5 cm² field.

Keywords: Dose Profile, Radiotherapy, Linear Accelerator, 6 MV Beam.

1 INTRODUCTION

Radiotherapy plays an important role in the care of cancer patients and is part of the control treatment of this disease. The ability of radiotherapy to help control tumor growth has stimulated interest in the treatment and it is possible to combine with immune-oncological agents and it is one of the most often used modalities of cancer treatment. Medical linear accelerators (LINAC) are widely used in modern radiotherapy, due to their flexibility and their high therapeutic reliability [1-3]. Radiotherapy techniques are perfectly integrated into the different therapeutic strategies used for the treatment of tumors and seek to prioritize dose deposition in the target tissue and reduce exposure of adjacent healthy tissues [4]. There are innovations in conformation methodologies, with the objective of greater preservation of healthy tissues surrounding the tumor, an increase in curative, ablative, or antalgic efficacy, and the technical evolution has introduced new theoretical and practical standards for ensuring the reliability of available radiotherapy techniques [5-6]. Radiochromic films can be useful for recording radiation dose distribution in the assessment of exposures in radiotherapy and diagnostic radiology and can provide an absolute dose measurement. These dosimetric films have a high spatial resolution, low energy dependence, wide dose range for radiotherapy, and equivalence close to human tissues, making them useful for measuring radiation fields with high-dose gradients. Radiochromic films are not sensitive to visible light and can be prepared in places where they are illuminated [7-9].

In this work, a LINAC X-ray beam of 6 MV was used in the irradiation of a solid water phantom, using fields of 10x10 and 5x5 cm². A solid water phantom loaded with the radio-chromic film was positioned twice at 1.0 m away from the focus of the X-ray beam. In the first irradiation, the solid water phantom was exposed laterally to obtain the longitudinal dose variation profile, and in the second irradiation, the phantom was irradiated frontally to obtain the axial dose variation. For irradiation, 300 Monitor Units were used (300 MU) equivalent to 1 cGy (centiGray) of absorbed dose, so the dose used was 3.0 Gy and traditionally, national and international codes of conduct provide guidelines on dosimetry with a reference field of 10x10 cm², considering that for larger fields, dosimetric parameters are well defined and can be accurately measured. A quality assurance procedure in the radiotherapeutic process, which checks the monitoring units (UM), calculated by a computerized treatment planning system, is extremely necessary to ensure that the dose to be released to the patient is accurate. For the chosen field, 5x5 cm², this work analyzes the effects of relatives to smaller fields [10].

The Technical Reports Series 483 published by IAEA (2017) treat the dosimetry of small static fields used in external beam radiotherapy and it is a code of practice for reference and relative dose determination. This code defines a small field subjectively and the field depends on the energy of the photon beam and the size of the field having scientifically three physical conditions to design a field as small: the loss of balance of charged particles; the partial occlusion of the primary photon of the source by the collimation devices and the size of the detector being large compared to the dimensions of the beam [11].

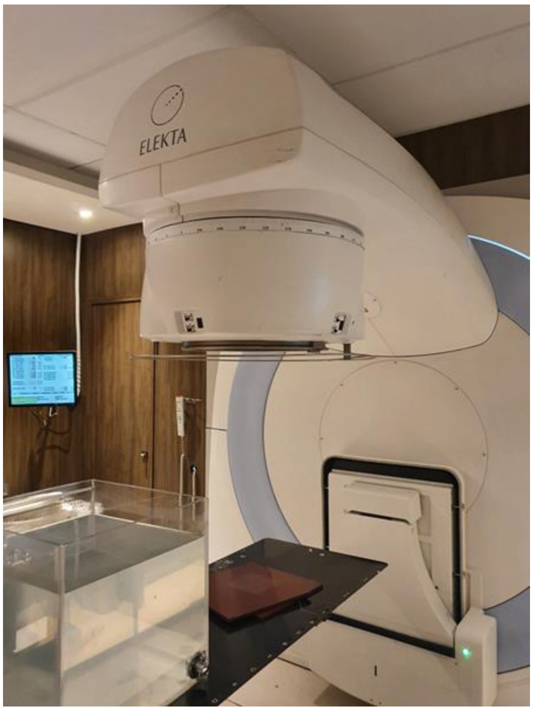
2 MATERIALS AND METHODS

The study was carried out in a linear particle accelerator for the production of a 6 MV photon beam. The photon beam is produced by energetic electrons striking a target generally constructed of tungsten due to its high atomic number to facilitate the production of photons by Bremsstrahlung. It used a linear accelerator, a solid water phantom, radiochromic film sheets for the recording dose profile, and a scanner for the generation of digital images of the film sheets to obtain dose variation data.

2.1 ELEKTA LINEAR ACCELERATOR

The linear particle accelerator used in experiments is equipment for the irradiation of patients. It is a linear accelerator of electrons, model Synergy Platform, from the manufacturer Elekta, which allows the generation of electron and photon beams. Photon beams can be generated at voltages of 6 and 10 MV. The leak radiation of the head is less than 0.1% of the dose rate in the isocenter, and the size of the field in the isocenter ranges from 1x1 to 40x40 cm², with multi-leaf collimator (MLC) that has 40 pairs and motorized physical filter with angles from 1º to 60º. The motorized physical filter has only an angle of 60º (in the planning/treatment, changing its inlet and output of the beam, we were able to make a filter between 1º to 60º). Fig. 1 illustrates the position of the solid water phantom charge placed in the accelerator at 1 m from the X-ray beam's focus to record the longitudinal dose profile [12-13].

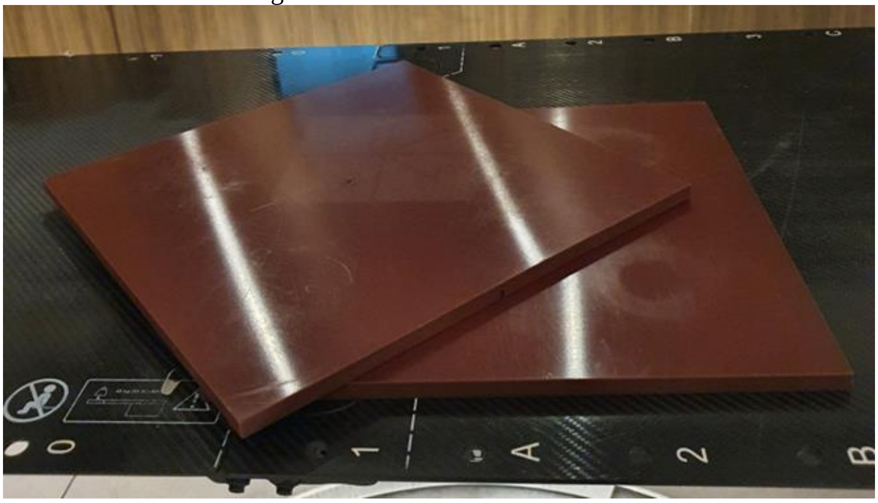
Fig. 1. Linear Accelerator Elekta and the Solid Water Phantom.



2.2 SOLID WATER PHANTOM

The phantom allows the placement of radiation detectors in a solid material and can substitute water. According to the manufacturer, the constitutional standard allows obtaining calibrations within 1% of the actual dose error in water, in particular, the solid water used disperses and attenuates radiation in a way close to the water and has dimensions close to 30x30x2 cm³ divided between plates. The search for data concerning dose distribution usually occurs in solid water simulators, as they approach the absorption and dispersion properties of radiation from muscles and other soft tissues [14]. Figure 2 presents an image of the solid water plates.

Fig. 2. Solid Water Phantom Plates.



2.3 RADIOCHROMIC FILMS

The film GAFCHROMIC, model EBT QD+ was used in the experiments. Since the 1960s, radiochromic film has been an accurate dosimetric tool used to verify the photon beam properties for different field sizes and energies. Quality Control is an important component in the quality assurance programming of the radiotherapy chain. For Quality Control purposes, the Gafchromic EBT3 film was used to verify the dose profile of the photon beam. It has construction characteristics similar to other models of radiochromic films. EBT dosimetry film is made by laminating a sensitive layer between two layers of polyester and it is used for measurements of absorbed doses in a range of 0.4 to 40 Gy, making it more suitable for applications in radiotherapy and radiosurgery. These are based on polydiacetylene dyes that have a high spatial resolution, low energy dependence, wide dose range for radiotherapy, and equivalence close to human tissues, making them useful for measuring radiation fields with high-dose gradients. The sensitivity of radio-chromic films is commonly defined as the rate of change in optical density and the amount of dose that causes color change when irradiated and represents a tool for the analysis of radiation dosimetry and is commonly used as absolute dose measurement systems [15-16].

2.4 PHANTOM IRRADIATIONS

Radiochromic film sheets were placed inside the solid water phantom in two positions and the irradiation was done twice. First, the film sheet was placed in the middle of the plates with one edge along the edges of the solid water plates (longitudinal irradiation). This sandwich was irradiated by the X-ray beam entering the surface where the film edge was located. In this exposition, the depth dose variation was recorded. In the second set-up, the film sheet was placed in the middle of the plates in the central area (axial irradiation). The charged phantom was irradiated frontally with the film sheet at 1.0 cm depth. In these exposures, axial dose variations in the X and Y axes were recorded. The load of the film sheets and the incidence of the X-ray beam on the phantom are illustrated in Fig. 3.

Fig. 3. Radiochromic film positioning into the water phantom.

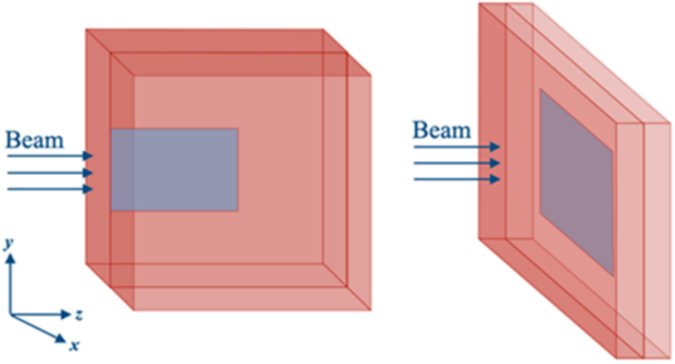
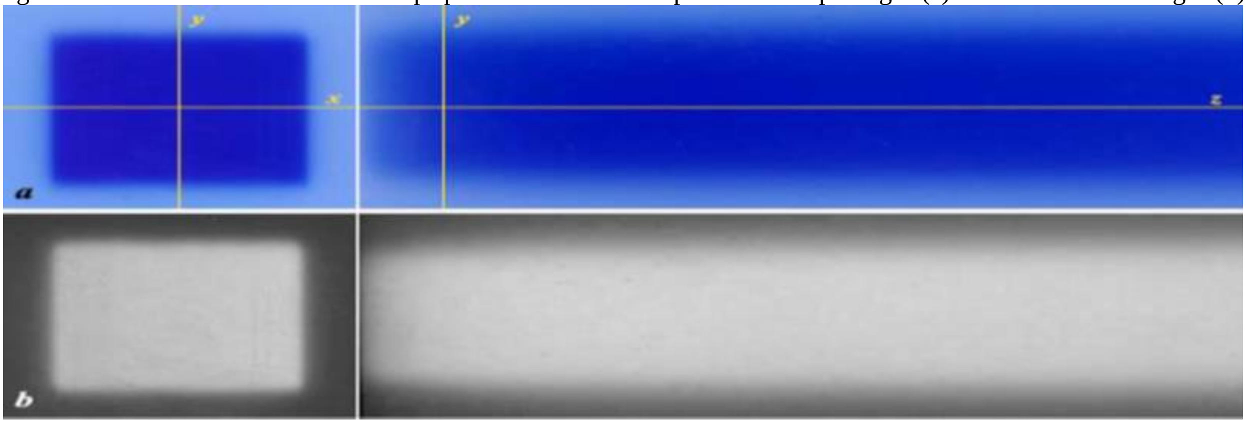


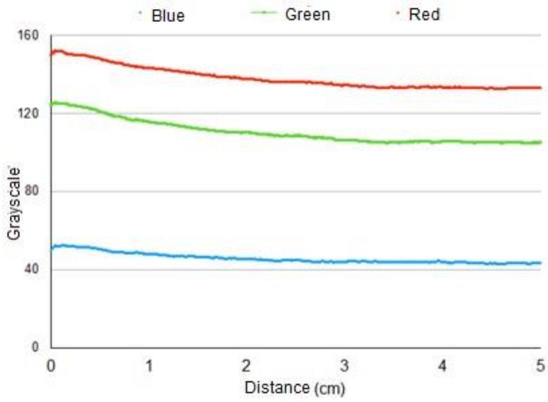
Fig. 4 has two images of the irradiated film strip for a field of 5x5 cm^2, one in axial (frontal) irradiation and another in longitudinal (sidewall) irradiation. In these images, axial irradiation corresponds to the letters X and Y, and longitudinal irradiation corresponds to the letters Y and Z. The graphs and images were worked on the red channel to obtain the dose variations graphs due to a better response. Fields were irradiated with a 6 MV photon beam with a dose rate of 300 MU/min which is equal to 3.0 Gy. The strips of radiochromic films were cut according to the size of the irradiation fields. For the 5x5 cm^2 field, the strips were made in a size of 7x7 cm^2, and for the 10x10 cm^2 field, the strips were made in 12x12 cm^2.

Fig. 4. Irradiated radiochromic film strips placed into the water phantom. Strip images (a) and red channel images (b).



The images in b were worked in the software ImageJ where the color split tool was used to obtain the images of the channel red. Then the grayscale inversion is performed on the red channel image. Grayscale inversion is required to correlate the lightest color with the highest absorbed dose value. This color channel was used because the grayscale values in this channel are higher than those presented by the green and blue channels. The highest recorded dose value corresponding to the lightest register that appears in the film image worked on image J. This will be the highest numerical value in grayscale. Therefore, the red channel was chosen for the recording of doses, as it has the highest numerical value and a greater amplitude than the green and blue channels. The graph presented in Fig. 7 contains the response curves related to the images of the three channels on the central longitudinal axis (Z).

Fig. 5. Darkening response of an irradiated film strip, per RGB channel.

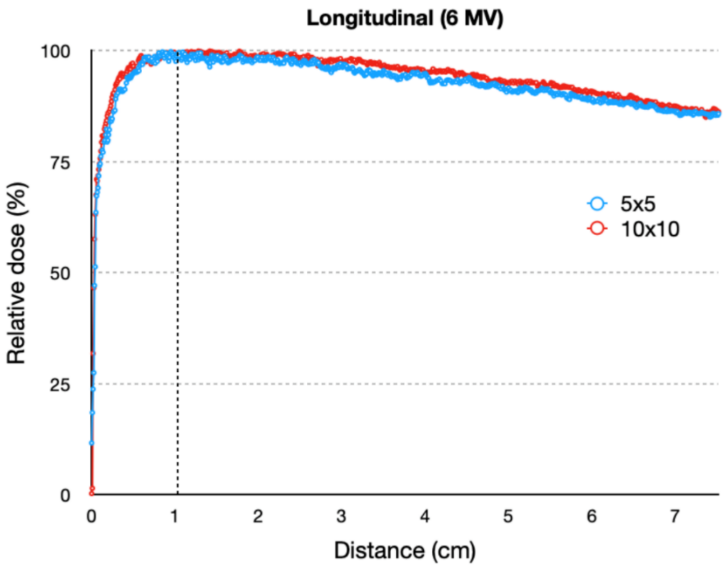


3 RESULTS AND DISCUSSION

3.1 LONGITUDINAL DOSE PROFILE

Fig. 6 shows the longitudinal chart, the maximum peak for the fields of 5x5 cm² and 10x10 cm² occurs at a distance of 1.30 cm (maximum point). At 1 cm depth, the irradiation to the 5x5 cm² field has 98.32% of the maximum relative dose, while for the field of 10x10 cm², the maximum relative dose is 99.12%. The decay of the absorbed dose values occurs with the increase in the distance reached by the X-ray beam. At 7 cm depth, the relative absorbed dose corresponds to 86.3% and 87.4%, respectively. The depth absorbed dose value represents the attenuation of the photon beam and the dose delivered to the surface so that there is a sharp drop in the dose with depth. Radiation beam incidence was perpendicular to the surface of the water phantom. The percent depth doses (PDD) and lateral dose profiles were acquired at depth of 100 cm source to surface distance (SSD).

Fig. 6. Irradiated radiochromic film strips placed into the water phantom. Strip images (a) and red channel images (b).



Tab. 1 presents parameters obtained about the relative absorbed dose in depth for the field 5x5 cm² and 10x10 cm² irradiated with an energy of 6 MV.

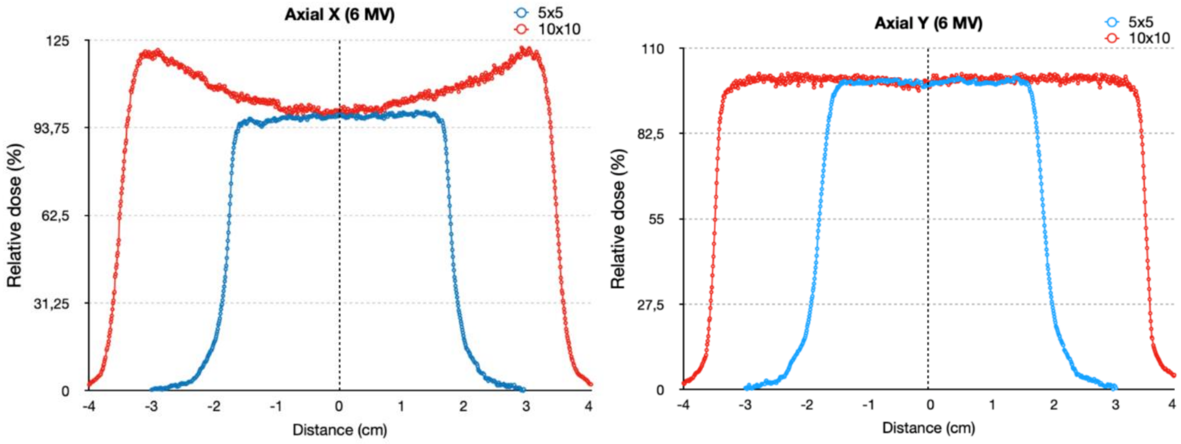
Tab. 1. Parameters about Longitudinal Dose for the Fields

Longitudinal Field (cm²)	Background Maximum Relative Dose (%)	Maximum Relative Dose (%)	Value 1.0 cm Relative Dose (%)	Standard Deviation (SD)
5x5	83.58 53.19	100.0	98.32	1.19
10x10		100.0	99.12	0.63

3.2 AXIAL DOSE PROFILES

Fig. 7 shows the relative dose variation in the frontal irradiation of the phantom to the X and Y axes using fields of 5x5 cm² and 10x10 cm². These data were recorded at a depth of 1 cm in the phantom. For the 5x5 cm² field the maximum relative dose value recorded was 99.4% of the maximum reference dose value for the X-axis and 100.64% for the Y-axis. For the 10x10 cm² field, the maximum relative dose value recorded was 122.2% of the maximum reference dose value for the X-axis and 101.7% for the Y-axis. The plateau in the central region of the dose variation curves presented a domed characteristic with an increase in the dose towards the field edges on the X axis to the 10x10 cm² field. In the center of the chart, the relative dose values recorded were 98.3% to the 5x5 cm² field and 99.1% to the 10x10 cm² field.

Fig. 7. Relative dose variation in frontal phantom irradiation recorded 1 cm depth for 5x5 cm² and 10x10 cm² fields.



Tab. 2 illustrates parameters obtained about the relative absorbed dose in axial irradiation for the field 5x5 cm² and 10x10 cm² irradiated with the energy of 6 MV.

Tab. 2. Parameters about Axial Dose for the Fields

Axial Irradiation	Vxmed (%)	Vymed (%)	Vmax (%)	Standard Deviation (SD)
5x5	97.47	99.00	99.37	0.74
10x10	106.63	99.78	122.21	0.63

4 CONCLUSION

The relative dose variations of a solid water phantom irradiated by a 6 MV beam for the 10x10 cm² and 5x5 cm² fields were obtained. The maximum absorbed dose recorded in LINAC was 3.0 Gy (300 Monitor Units). Axial graphs were obtained with frontal irradiation of the phantom object with the film positioned at 1 cm depth. The X and Y axis graphs allowed us to observe the variation of the dose distribution according to the size of the field used, the central dose plateau, and the dose deposition outside the field as a function of the scattered radiation produced in the interaction of the primary beam with solid water. Comparing the X and Y curves of the 5x5 cm² and 10x10 cm² field, it is possible to observe the differences in the central slope of the curve and on the ascent and descent, which is so greater on the X-axis. The plateau is concave on the X-axis and convex on the Y-axis. The variation of the deposited dose in depth on the central axis was very similar for both fields and the maximum dose value happens at 1.30 cm depth when parsed in point for the two fields. In the 10x10 cm² field, for the frontal irradiation performed, only the X axis, the 10x10 cm² field presented the plateau region differently from the 5x5 cm² field with an increase in the dose near the edges of the field.

These variations could occur due to the Flattening Filter Free (FFF) primary. Flattening filter-free (FFF) beams generated by medical linear accelerators are today clinically used for stereotactical and non-stereotactical radiotherapy treatments. Such beams differ from the standard flattened beams (FF) in the high dose rate and the profile shape peaked on the beam central axis. Removing the flattening filter increases beam intensity, especially near the central axis. Increased intensity reduces treatment time, especially for high-dose stereotactic radiotherapy/radiosurgery (SRT/SRS). Furthermore, removing the flattening filter reduces out-of-field dose and improves beam modeling accuracy. FFF beams are advantageous for small-field (e.g., SRS) treatments and are appropriate for intensity-modulated radiotherapy (IMRT). For conventional 3D radiotherapy of large targets, FFF beams may be disadvantageous compared to flattened beams because of the heterogeneity of the FFF beam across the target (unless modulation is employed). For any application, the nonflat beam characteristics and substantially higher dose rates require consideration during the commissioning and quality assurance processes relative to flattened beams, and the appropriate clinical use of the technology needs to be identified. Consideration also needs to be given to these unique characteristics when undertaking facility planning. Then, the most difference in the X-axis to 10x10 cm², therefore, the use of the 5x5 cm² field is more indicated for less differentiation about the dose. For the Y-axis, the maximum relative absorbed dose parameter, in the fields of 5x5 cm² and 10x10 cm², are very close, with minimum differences.

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