

Original Article

The Quality Control of Intensity Modulated Radiation Therapy (IMRT) for ONCOR Siemens Linear Accelerators Using Film Dosimetry

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Abstract

Introduction

Intensity Modulated Radiation Therapy (IMRT) has made a significant progress in radiation therapy centers in recent years. In this method, each radiation beam is divided into many subfields that create a field with a modulated intensity. Considering the complexity of this method, the quality control for IMRT is a topic of interest for researchers. This article is about the various steps of planning and quality control of Siemens linear accelerators for IMRT, using film dosimetry. This article in addition to review of the techniques, discusses the details of experiments and possible sources of errors which are not mentioned in the protocols and other references.

Materials and Methods

This project was carried out in Isfahan Milad hospital which has two Siemens ONCOR linear accelerators. Both accelerators are equipped with Multi-Leaf Collimators (MLC) which enables us to perform IMRT delivery in the step-and-shoot method. The quality control consists of various experiments related to the sections of radiation therapy. In these experiments, the accuracy of some components such as treatment planning system, imaging device (CT), MLC, control system of accelerator, and stability of the output are evaluated. The dose verification is performed using film dosimetry method. The films were KODAK-EDR2, which were calibrated before the experiments. One of the important steps is the comparison of the calculated dose with planning system and the measured dose in experiments.

Results

The results of the experiments in various steps have been acceptable according to the standard protocols. The calibration of MLC and evaluation of the leakage through the leaves of MLC was performed by using the film dosimetry and visual check. In comparison with calculated and measured dose, more than 80% of the points have to be in agreement within 3% of the value. In our experiments, between 85 and 90% of the points had such an agreement with IMRT delivery.

Conclusion

The EDR2 films are suitable for quality control of IMRT. According to complexity of the quality control for IMRT, the physicists of each center have to develop specific guidelines according to their equipments and limitations. An accurate treatment planning system with capability of inverse planning is an essential need for IMRT. The result of the planning system has to be compared with experiments in various situations.

Keywords: Film Dosimetry, Intensity Modulated Radiation Therapy, Quality Control

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1. Introduction

One of the main goals of radiation therapy is delivering the maximum dose to the tumor and minimum dose to the normal tissue and all of the new advances and techniques are developed to achieve this goal. Intensity Modulated Radiation Therapy (IMRT) is one of the most important steps in optimization of radiation therapy. In this method of radiation therapy, not only the isodose surfaces with high values are conformed to the tumor surface, but also, the low level isodose surfaces are conformed to critical organs in vicinity of the tumor [1, 2].

IMRT technique is a new method compared with 3D conformal technique [3-4]. In 3D conformal, using Multi Leaf Collimators (MLC), the prescribed dose is delivered to the tumor with high precision. In this method, the "forward planning" is used in which the MLC leaves from various angles are conformed to the tumor and the appropriate margin. The main difference of the forward planning with IMRT is that, in the former, the radiation intensity is uniform in each beam but in the latter, each beam is divided to many (hundreds to thousands) smaller beams called "segments" and each segment has its own intensity. The treatment planning method in IMRT is called "inverse planning" which is a totally different concept compared with forward planning. Inverse planning is done using the treatment planning computer in the way that the dose to the critical organ is usually less than forward planning [5].

From innovation of IMRT 30 years is passed and currently this method of treatment is a common technique in many centers [6-8]. In the other hand, considering the complexity of this method in various steps such as machine preparation, quality control, and inverse planning, many researchers are interested in IMRT related topics [9-16]. For example, in recent years we have seen the development and progress of Tomotherapy which is a dedicated machine to IMRT [17-20]. This machine is equipped with therapy and imaging devices at the same time, which delivers the

dose to the patient in a similar manner to spiral CT scan.

This article is a report consisting of various steps of quality control for IMRT method with MLC using film dosimetry, which is performed in Isfahan Milad Hospital, Iran. One purpose of the article is to mention the points and difficulties in the performance of various steps, which are not mentioned in other articles. The general references used during this project were the AAPM reports, reliable review articles, and close visit of IMRT quality control in McGill University Health Center [1, 2, 6, 9, 21-24].

The Isfahan Milad hospital is equipped with two ONCOR linear accelerators (Linac) from Siemens with MLC which have the capability of IMRT dose delivery and treatment planning. In the following sections, the various steps and points for quality control is presented.

2. Materials and Methods

2.1. The Concept of Inverse Planning

One of the main differences of IMRT and 3D conformal techniques is the inverse planning. The concept of inverse planning is described in Figure 1. In this Figure, the critical organ (organ at risk) is surrounded by the tumor. The tumor is irradiation from four different directions, as such that the intensity of the radiation in each field is not uniform. The design of the variation of intensity in each field is performed by the treatment planning software and related mathematical algorithms. However, conceptually, the intensity of radiation in each point is proportional to the thickness of the tumor on that direction and it is inversely proportional to the thickness of the critical organ in that direction. The mathematical algorithm for calculation of the radiation intensity is very complicated and it is similar to the image reconstruction method in CT scan [6].

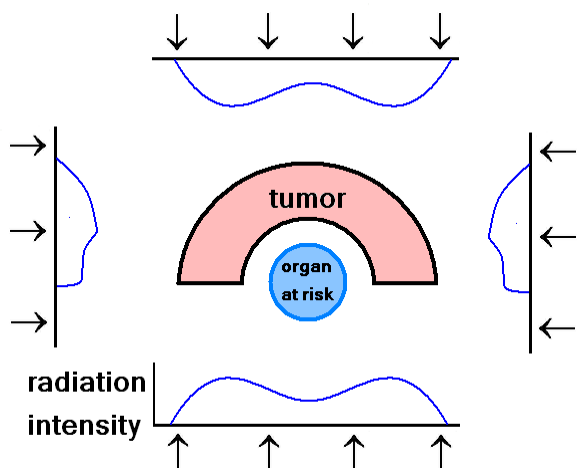


Figure 1. An example of four radiation fields with non-uniform intensity in IMRT.

2.2. Verification and Quality Control of MLC

There are two techniques of IMRT which are based on MLC movement during the radiation delivery. If the shape and position of the MLC during irradiation of each segment is fixed and not moved, this method is called step-and-shoot IMRT. If the MLC leaves move at the time of irradiation, this is called dynamic IMRT [25-27]. In ONCOR Linac, only step-and-shoot method is possible and the dynamic IMRT is feasible by Varian Linacs [28-30].

Considering the fact that each IMRT field is a combination of many segments with various intensities, determination of MLC leaf positions and penumbra should be performed with high accuracy. The width of the penumbra should be measured using a detector with high spatial resolution and imported to the treatment planning software. In general, the position of the MLC leaves should be measured with accuracy of 1 mm or better. The matching of light field and radiation field with high accuracy should also be checked by physicists.

In this section, two experiments recommended in AAPM protocols [1, 2], were done for quality control of the MLC as follows:

1- In the first experiment, the collimators remain open in a $2 \times 10 \text{ cm}^2$ rectangular field and a film is irradiated. Afterward, the film is moved 2 cm in the width in the way that the new field is matched to the border of the previous field. This movement is done with

moving the couch. The 1.5 cm slab as a build up should be placed on the films for 6 MeV photons. The film is irradiated with multiple rectangular field tangents to each other. The goal is to check the match of the field size in all MLC leaves. The type of film in these experiments is EDR2 film from Kodak which is calibrated before the experiment. The film calibration should be done exactly according to Zeu et al. [31] and Childress et al. [32, 33] recommendations to avoid unwanted errors. Some details of calibration are discussed in the next sections.

2- In the second experiment which is one of the accurate and important evaluations, the collimator leaves are closed completely and the film is irradiated in this way. A line of radiation due to the leakage remains in the film. Then, the closed MLC leaves are moved 2 cm perpendicular to tangent line and are irradiated again. The processed film finally includes few parallel lines 2 cm away from each other. The "thin" and "uniform" lines by visual check indicate a good calibration. Any kind of non-uniformity indicates inappropriate calibration of the MLC on the related leaf and the calibration is needed. According to AAPM protocol [2], this test evaluates the position of the MLC leaves with 0.2 mm accuracy.

One difficulty in this experiment is that the value of leakage through the closed MLC leaves is not known. Therefore, in a separate experiment, a film is irradiated with closed MLC with 100 to 1000 MU (Monitor Unit), 6 MV photons. After development of the field, the appropriate value was determined to be between 300 and 500 MU.

A very important point which is hidden in Siemens Linac setup which prevents us to do this experiment is that, with closed MLC, the irradiated area becomes zero. For zero field size, the secondary collimators which are placed before MLC are closed and we have no radiation. To prevent this, one has to keep the first and the last leaf of MLC open a few centimeters. This configuration keeps the secondary collimators wide open. As

illustrated in Figure 2, the rest of the leaves are closed but first and last leaves are left open.

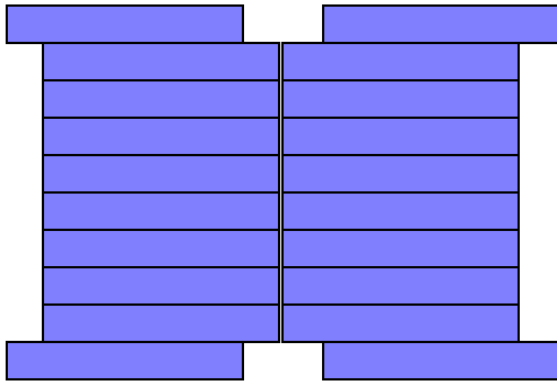


Figure 2. The setup for MLC in radiation leakage experiment. Two pairs of leaves, at two ends, are 2 cm open to keep the secondary collimator open.

2.3. Inverse Planning for IMRT

As mentioned in section 2.1, in inverse planning, one has a different concept compared with the conventional planning. In forward planning, this is the user that determines the direction, intensity, and size of the fields to get the acceptable dose distribution. In inverse planning, the user, after contouring the tumor volume and other organs, determines the dose constraints for each organ. Afterward, this is the software that determines the field sizes and intensity maps using an iterative algorithm. Through this process, the goal is to get the dose as close as possible to the dose constraints of the user. In this step, the user with knowledge and experience of inverse planning should change the input parameters for a better result. One input example is the number of the fields; more fields give more possibility to get the desired dose distribution [35, 36], and this input also makes the treatment more expensive. The input parameters are different in various planning systems however in general there are two groups of input parameters:

- 1- The maximum dose to the tumor and minimum acceptable dose.
- 2- The maximum acceptable dose to critical organs.

For inverse planning, careful contouring of various organs by medical doctors is necessary and it is a time-consuming process. Because of the nature of the inverse planning and the usage of many segments close to each other, there is a possibility of the hot spots in the entire irradiated volume. Therefore, in some cases even the contouring of normal tissues are important [37]. The treatment planning system, used in this project, is TiGRT [38]. This software as well as inverse planning has the capability of image fusion in which the contouring can be performed with fused MRI and CT images with high accuracy [39].

The physics algorithm for transport of the particles to calculate the dose has its own importance, because the radiation fields are usually small and the lack of the electron equilibrium is possible. For this reason, the accurate planning software based on Monte Carlo technique is under development and usage [40-45].

2.4. Quality Control of Planning System and Dosimetry

For purpose of treatment planning quality control and dosimetry, many configurations and combinations of dosimetry set-up have been suggested in the references [1, 2]. This group of checkings varies from simple two-dimensional tests to complicated three-dimensional models. The goal of these tests is to assess the ability of the treatment planning system in generating the desired dose distribution [46-48].

For quality control purpose, in one step, it is evaluated that to what degree the treatment planning system can produce the desired dose distribution. After this step, the created plan is applied to a phantom with dosimetry setup and the measured dose is compared with the calculated dose in treatment planning system. For dosimetry of IMRT fields, one can use film dosimetry, ionization chamber, or detector arrays such as the Map Check [49].

It should be noted that the manual transfer of the treatment plan from the software to the linear accelerator is almost impossible. The

plan after approval is transferred to the ONCOR Linac using LANTIS, the comprehensive software for administration of radiation therapy.

2.4.1. Film Calibration

The EDR2 film from Kodak has been used for dosimetry. Considering the linear response curve of this film in relatively wide range of dose, up to 600 cGy, the EDR2 film is one of the most proper types for two-dimensional dosimetry in radiation therapy [31-34]. Another choice is radiochromic films which are not used widely on a daily basis because of their high price.

The film calibration using MLC has its own points which should be considered to avoid calculation errors. The film calibration in general is done with multiple rectangular fields and different dose values. The dose is increased step by step from 50 cGy to 600 cGy and then the calibration curve is plotted. The field size for each section is $2 \times 10 \text{ cm}^2$ [31]. An important point for experiment is that each region should be placed above the last region and not beside the region (Figure 6). In the second case, although it appears that the outside of the field is blocked and no radiation is delivered to the last region, but the interleaf leakage in MLC may affect the dose regions around the field. In the correct case, the secondary collimators limit the beam in upper and lower border and there is no leakage.

The developed films should be scanned with dedicated film scanners. These scanners have the ability of scanning the negatives in large sizes. The type of the scanner in this project was "Mikroteck, ScanMaker 9800, plus". The resolution of the scan was 300 dpi and it was in the gray scale format. During film development, any kind of high pressure and impact result in the darkening of the film, and therefore we get unwanted dark points and peaks in dose calculation. The presence of the dust also leads to some dots in the scan and gives considerable errors so before the scanning, the clarity of the scanner and the films should be checked. In the first scans of

this project, the presence of dust and impact of the sharp objects to the film made many unwanted errors in dosimetry.

2.5. Quality Assurance

The IMRT technique from QA point of view includes the following parts to be checked: patient immobilization, three-dimensional imaging, inverse planning, patient positioning during irradiation, and the dose delivery. It should be noted that the AAPM reports number 40 and 53 [50, 51] include the general quality assurance procedures and they are not adequate for IMRT QA.

Quality assurance in 3D conformal technique is only based on system parameters and it is not repeated for each particular patient [7]. Moreover, this conventional method is not applicable for IMRT. In IMRT, prediction of all possible problems is very difficult therefore the treatment plan and the delivered dose for each patient have to be checked [8]. For this purpose, the delivered dose for each particular patient without any change is applied to a QA phantom for dosimetry. The method of dosimetry is usually ionization chamber and film dosimetry. The QA phantom is scanned with CT and the 3D image is imported to the treatment planning system. The patient plan is applied to the QA phantom and the dose distribution is calculated. It should be noted that this ability (transferring the patient plan to the QA phantom) should be available in the treatment planning system. The treatment control and the level of the match between the calculated dose and the measured dose are evaluated in two steps:

- 1- The dose distribution in the film is compared with the calculated dose in each region. The film is scanned with a negative film scanner and then, using the computer and the calibration curve, the dose distribution is derived from the film surface. The dose in all points of the film is compared with the related points in the simulation using the treatment planning software. If more than 70% of the related points have less than 3% of difference, the quality control of the plan is acceptable.

2- The dose value in one point of the phantom should be measured directly in the ionization chamber and the measured value is compared with the calculated dose with treatment planning software. The difference should be less than 3-4%. The position of this point is better to be placed in a point with high dose and low dose gradient [47]. With this choice of the point, the measurement and comparison of the dose is done more accurately.

Each of the above tests has to be repeated by a physicist for each patient. This test includes the quality control of most steps of the treatment such as correct data transfer from treatment planning system to the linear accelerator.

In this section of the project, many experiments are performed for evaluation of the treatment planning software and the accuracy of the delivered dose and one of the most important of which is presented here. This experiment is based on the TG119-AAPM recommendations [1] and simulates one of the most common cases in IMRT, in which the tumor surrounds the critical organ. The size of the tumor cross section as well as

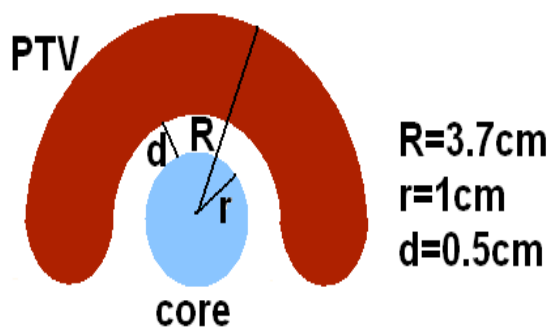


Figure 3. The cross section of the contour used for quality control of the treatment planning. In this design, the target surrounds the critical organ, the core, like a C shape.

the needed margin (GTV: Gross Tumor Volume, CTV: Planning Tumor Volume) is illustrated in Figure 4. This experiment is called the C shape target [10]. In the Figure, the length of the PTV is 8 cm and the length of the core is 10 cm. This plan is designed in a uniform water phantom or solid water phantom. The result of the treatment planning is evaluated for various prescribed doses. In the first case which is a simpler case, the dose of the core (critical organ) should be remained up to 50% of the prescribed dose of the PTV. In the second case, the dose of the core has to be up to 20% of the PTV. This is a more difficult problem compared with the first case. The prescribed dose of PTV in both cases is 50 to 55 Gy. The number of the fields is 9 beams with 40 degree spacing around PTV and this starts from 0 degree gantry angle. All of the above numbers are derived from TG119. These numbers are entered in treatment planning software and the software via inverse planning creates a dose distribution, close to the prescribed dose.

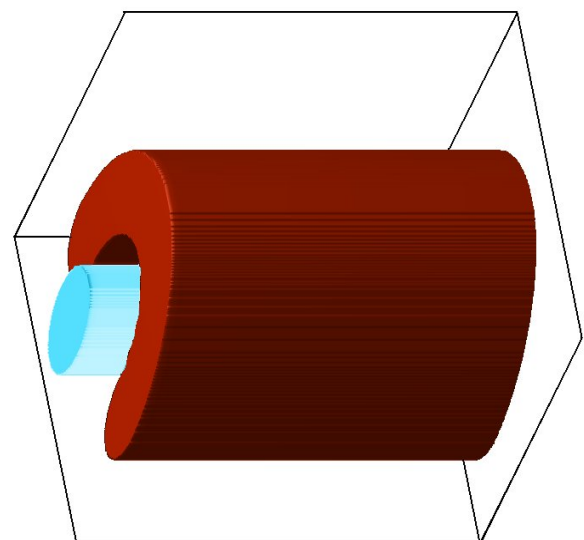


Figure 4. Three-dimensional view for the contour of Figure 10. According to TG119 recommendation, the length of the PTV is 8 cm and the length of the PTV (the core) is 10 cm.

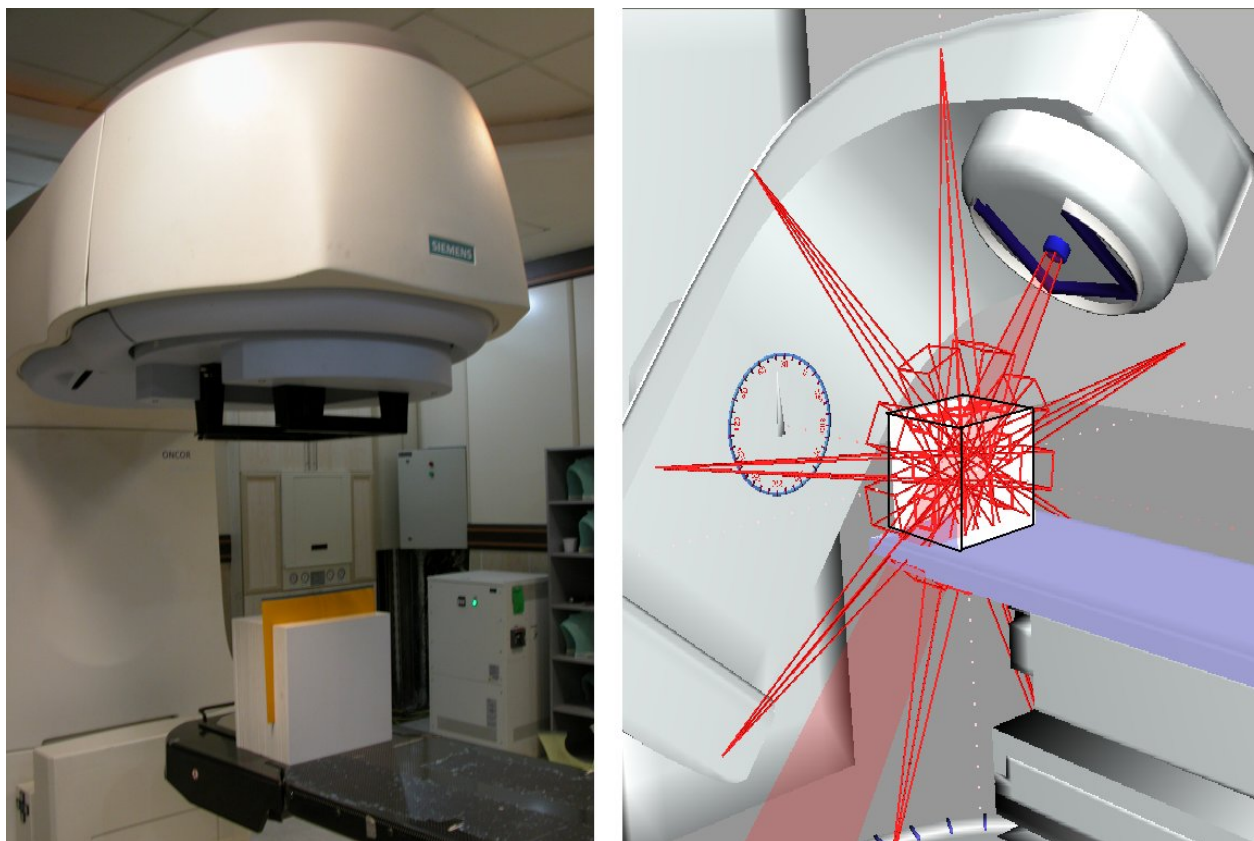


Figure 5. The position of the PMMA phantom in ONCOR Linac couch with a film which is used for quality control in the C shape target. The Linac irradiates the film from 9 different angles.

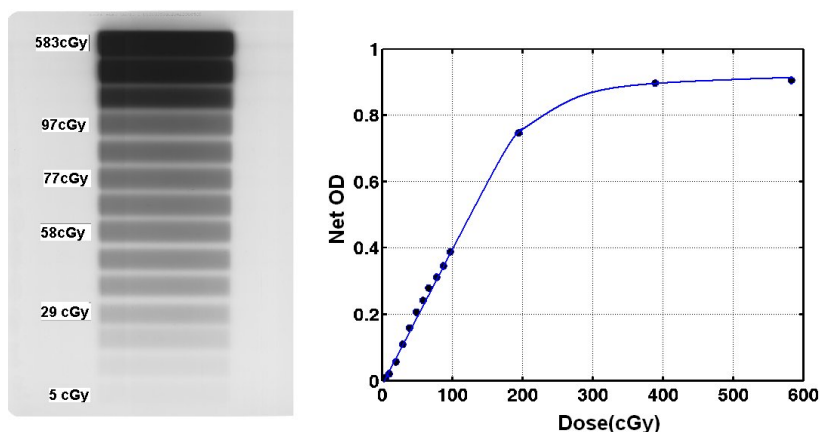
For evaluation of the final result of the treatment, in one step, the resulted dose distribution from treatment planning is checked and in another step these results are compared with the experimental dosimetry results. In results of the treatment planning software, the ability of the software to produce the desired dose distribution is checked.

For dosimetry, the treatment plan is transferred to the control computer of the Oncor Linac. A cube phantom is made by PMMA (Poly Methyl-Meth Acrylate) slabs and an EDR2 film is placed between these slabs in the related depth. The direction of the field is in a way that the surface of the film is perpendicular to the core axis and PTV length (Figure 5).

3. Results

3.1. Film Calibration

The irradiated EDR2 film and its calibration curve are presented in Figure 6 (A & B). The film was irradiated with 6 MV photons and optical density of the developed film, were measured by scanner and they are used to plot the calibration curve. As mentioned before, the field size was $2 \times 10 \text{ cm}^2$ and the dose value varied from 5 to 600 cGy. The dose in each strip should be measured directly using an ionization chamber in a separate experiment with a similar setting. As illustrated in Figure 6, the calibration curve is linear over a wide range of the absorbed dose. More details of the experiment and the related formulation are available in references 31-34.



$$I \leftarrow \text{Film} \leftarrow I_0 \quad OD = \log_{10} \left(\frac{I_0}{I} \right)$$

Figure 6. The calibration curve of EDR2 film. The irradiated film is also illustrated in the left. Few numbers of the related dose irradiated to the strips are shown.

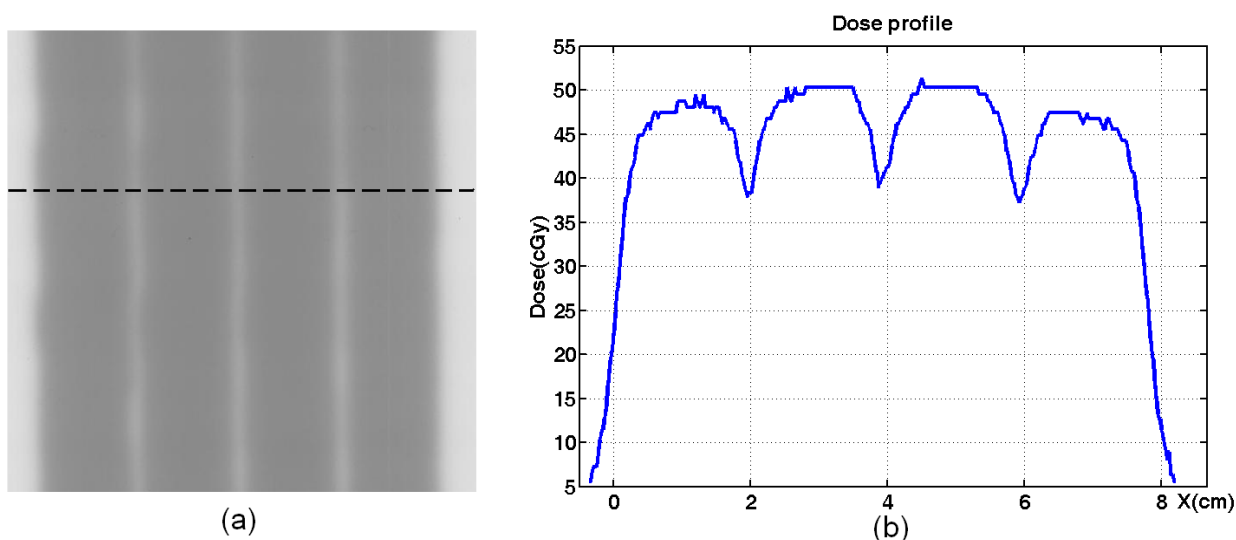


Figure 7. a) The MLC test that abuts irradiated strips with 2 cm distances, b) The dose profile along the dashed line in Figure (a).

3.2. The Quality Control of MLC

In this section, the results of the two experiments for MLC quality control are presented. The first experiment is the abutted 2 cm strips which is illustrated in Figure 7-a. In this experiment, the radiation fields are 4 rectangular fields placed 2 cm from each other so the edge of the fields abuts. Using the

calibration curve, the dose is calculated in all points of the field. The results of the dose calculation are illustrated in Figures. 7 and 8 as a profile and 3D surface. All of the curves and Figures are plotted using MATLAB software.

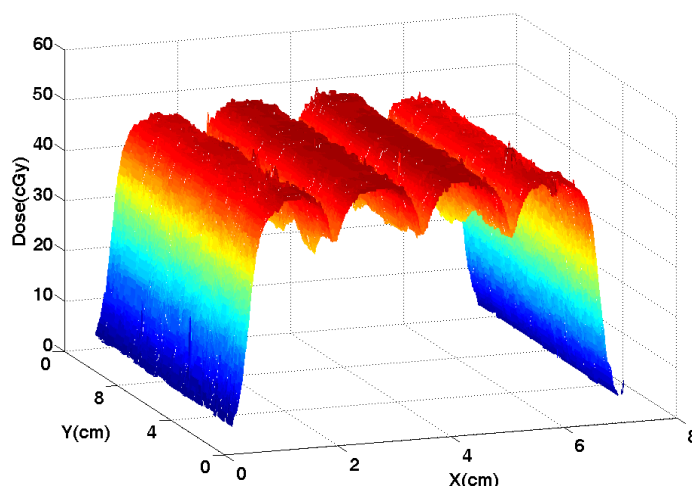


Figure 8. The dose distribution for all points in the abutted rectangular fields in Figure 7.

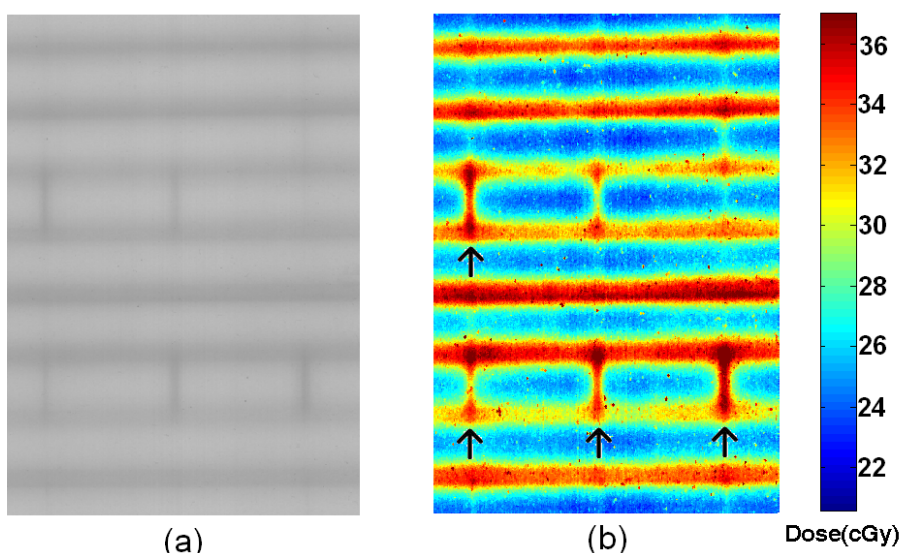


Figure 9. Leakage test for a completely closed MLC stat, a) The irradiated EDR2 film, b) The dosimetry results in Colormap format. The arrows illustrate the high level of the leakage on those points, indicating that the leaves are not closed completely and need adjustment.

The second experiment is similar to the first one but with closed MLC leaves. In this experiment, the quantity and uniformity of the leakage through the leaves are verified. Following delivery of each irradiation with amount of 300 MU, the MLC is moved 2 cm across the field's width. The results of this experiment are illustrated in Figure 9. The Figure 9.b illustrates the result of the irradiation in Colormap format. For checking the results of this part, it should be noted that the horizontal lines are related to the interleaf leakage which exist anyway [2]. The adjacent leaves are always sliding into each other and

although they are in close contact but there is still some small leakage of radiation from the minute gaps between leaves.

The vertical lines in Figure 9.b illustrate the leakage between two opposed leaves in MLC. In the points that MLC is closed completely there is a small leakage and we have a uniform line. As illustrated in the Figure with arrows, there are few points at which there are visible gaps between leaves and the amount of leakage is considerable.

3.3. The Results of the Treatment Planning for IMRT

The result of treatment planning for the desired dose distribution (section 2-5) is illustrated in Figure 10. These results are derived with these dose constraints: 5000–5500 cGy for PTV, and maximum 1000 cGy for the core (20% of PTV). This plan is delivered in a cube PMMA phantom with 30 cm dimension. The curves in Figure 10 illustrate the final dose distribution results. As mentioned before, in this plan each of the 9 fields includes many segments that their combination at the end generates the final dose distribution.

The results of film dosimetry for C shape target are illustrated in Figure 11. Figure 11.a illustrates the developed film after IMRT radiation and part b illustrates the resulted dose distribution. The amount of the match between experimental and calculation dose is 82% for all points. This number means that in the dose measurement, 82% of the points in Figure 11 have less than 3% difference to the related points in Figure 10. This concept is related to Gamma index which is calculated with the software [52]. In this verification, using MATLAB, two images are registered and compared.

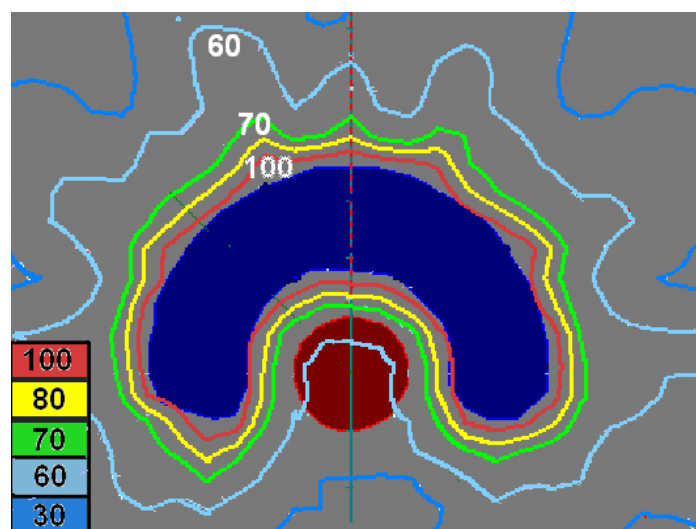


Figure 10. The isodose distribution related to the C shape target which is designed and calculated with treatment planning software.

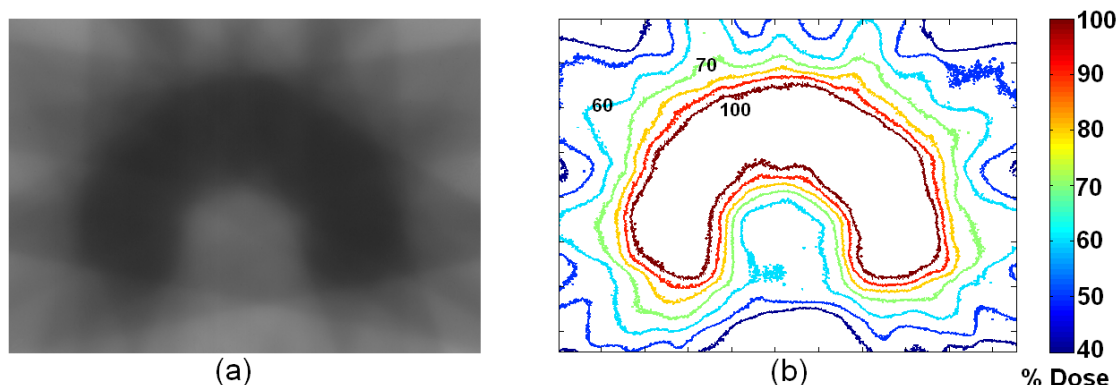


Figure 11. The film dosimetry results for C shape target. a) The irradiated EDR2 film, b) The isodose curves.

4. Discussion

The implementation of IMRT technique has its own points and difficulties in all parts of the technique. Currently, IMRT is a standard

method in the world and many books and articles are published for various aspects of this technique such as contouring, treatment planning, and quality control. In this project

using LANTIS, the comprehensive software for administration of radiation therapy, the entire sections of the clinic is in connection with each other such as: multi slice CT scan, the treatment planning software, and linear accelerators. With this system, the CT images are automatically exported to treatment planning and the IMRT plan is directly exported to the Linac. This ability minimizes the error due to data transfer [25].

In calibration step and film dosimetry, it is recommended that the films should not be developed sooner than one hour from the

exposure. According to Childress et al. report [33], the instability of the film in first hour from the exposure is more than 1%. As mentioned, the details of the film dosimetry and calibration should be done according to the reliable references [32-34].

In the abutted 2 cm rectangular fields, the uniformity of the profile demonstrated the acceptable calibration of the MLC. Figure 12 illustrates a sample of profile in which one of the match lines are not in the range of the other lines and in this case the MLC needs calibration.

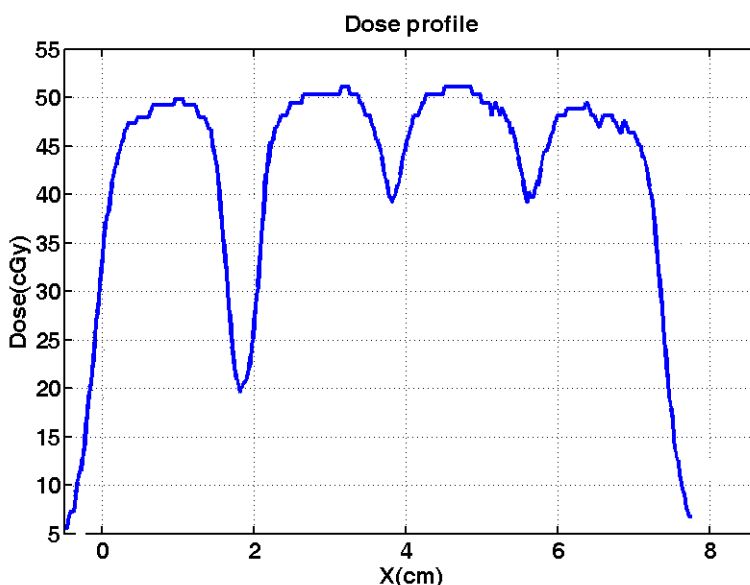


Figure 12. An example of the 2 cm abutted strips in which the MLC leaves are not calibrated properly, the first gap is deeper compared with other two gaps.

In the experiment with closed MLC leaves in which the opposed leaves are in contact, one should consider the difference between the Varian and Siemens Linacs. In Varian Linacs, the MLC leaves cannot be closed completely and it has to be 0.5 mm air gap between them [53]. Therefore, this experiment with Varian Linacs is only possible with 0.5 cm gap. This limitation is not applied to Siemens Linacs as seen in this project. For evaluation of the results in this section (Figure 9), it should be noted that the check of the leakage uniformity is done “visually” and no particular parameter is defined for uniformity of the line [2]. In this experiment, the visual check alone is adequate for determination of the errors.

In this project, many contours and various situations are designed; an important one of them is illustrated in Figures 3 and 4. The important point of this experiment is that derivation of such a dose distribution (Figure 11) in 3D conformal technique is impossible. Another important aspect of this experiment is its similarity to prostate cancer cases. In many prostate cancer cases and 3D conformal plans, the damage of the rectum wall is unavoidable. However, as seen the IMRT dose results, the high level isodose lines do not cross the core inside the tumor.

At the end, some general points of IMRT technique for physicists and radiation therapists are reviewed here [36]:

- The responsibility of the treatment results is on the physicist and radiation therapist doctor.
 - The determination of the equipment and treatment planning limitations is the responsibility of the physicist.
 - The treatment planning software should have the image fusion option.
 - Because in comparison with 3D conformal, the IMRT fields have a lower MU, the stability of the Linac output in low MUs should be checked [54,55].
 - The leakage of the MLC leaves should be verified [56-59].
 - The treatment plan of one system may not be feasible in another Linac. Therefore, in each center, QA and QC protocols have to be prepared according to equipments and limitations of that particular center [37].
 - Considering the high cost and complexity of the IMRT, the dose distribution of this method should be compared with 3D conformal method. If there is not a great improvement, the 3D conformal should be applied instead of IMRT [37].
 - The quality control of the dose distribution and point dose verification for "each patient" is unavoidable [60].
 - In patient management, it should be considered that IMRT is a time-consuming process in all aspects. The time of the treatment compared with 3D conformal technique is 1.5 to 2.5 times longer.
- In general, the more complicated the equipments and the methods, the more is the

risk and the variety of the errors. Therefore, specific quality control in all steps is recommended. In some pioneer centers, the start of IMRT was with just one patient in a week so there was enough time for physicists to check and verify all aspects of the process including the QA and dosimetry [61].

5. Conclusion

The quality control of the treatment planning software is a very broad topic for which many protocols and experiments are suggested. The goal of this work was to study various aspects of implementing IMRT after Siemens linear accelerators. This report is an attempt to address some details of the setup and measurements which are not available in the protocols and other references. This study presents some initial steps and this topic deserves further researches in various aspects of it.

Acknowledgment

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