Study on the Tongue and Groove effect of the Elekta Multileaf Collimator using Monte Carlo simulation and film dosimetry

Freddy Haryanto, Matthias Fippel, Annemarie Bakai and Fridtjof Nüsslin

Abteilung für Medizinische Physik, Radioonkologische Universitätsklinik, Hoppe-Seyler-Str.3, 72076 Tübingen, Germany

Abstract

Multileaf collimation of the treatment fields from medical linear accelerators is nowadays a common option. Due to the design of the leaf sides the tongue and groove effect occurs for certain multileaf collimator applications such are the abutment of fields where the beam edges are defined by the sides of the leaves. In this work, the tongue and groove effect has been measured for two pairs of irregular multileaf collimator fields that were matched along leaf sides in two steps. Measurements were made at 10 cm depth in a polystyrene-phantom using Kodak EDR2-films for a photon beam energy of 6 MV on an Elekta Sl*i*-plus accelerator. To verify the measurements full Monte Carlo simulations were done. In the simulations the design of the leaf sides was taken into account and one component module of BEAM code was been modified to correctly simulate the Elekta-multileaf collimator. The results of measurements and simulations are in good agreement and within tolerance of film dosimetry.

Keywords: Tongue and groove effect, multileaf collimator, Monte Carlo simulation

Zusammenfassung

Heutzutage werden zunehmend Lamellenkollimatoren für die Kollimierung von Strahlenfeldern eingesetzt. Zwar erreicht man mit Lamellenkollimatoren eine bessere Anpassung der Dosisverteilung an die Form des Zielvolumens, jedoch ist ihre Verwendung auch mit einigen Problemen bei der Dosisberechnung verbunden. Eines dieser Probleme, der Nut- und Feder-Effekt, wird in dieser Arbeit untersucht. Dieser Effekt ist besonders bedeutsam, wenn Feldanschlüsse zweier Felder bei einer Bestrahlung vorgesehen sind. Zur Untersuchung dieses Effektes wurden zwei Konfigurationen mit unregelmäßigen Paarfeldern eingesetzt. Die Messungen erfolgten in einem Polystyrol-Phantom mit Kodak EDR2-Filmen bei 6 MV Photonenstrahlung an einem Elekta-Linearbeschleuniger (SL*i* plus). Um die Messungen zu verifizieren, wurde der Beschleunigerkopf mit Hilfe des BEAM-Programmes modelliert. Zur Berücksichtigung des Nut- und Federeffektes wurde das BEAM-Programm entsprechend der Bauart des Elekta-Kollimators modifiziert. Messungen und Dosisberechnungen der Monte Carlo-Simulation ergaben gute Übereinstimmung.

Schlüsselwörter: Nut-und-Feder-Effekt, Lamellenkollimatoren, Monte-Carlo-Simulation

1. Introduction

Since several years, the computer controlled multi leaf collimator replace compensators for conformal radiation therapy. Step-and-shoot and the dynamic multileaf collimator are two well-known techniques based on the multileaf collimator and are used to deliver intensity modulated radiotherapy. At the Tübingen University Hospital the first of these techniques (step-and-shoot) is used with an Elekta-Sl*i*-plus Linac equipped with the Elekta multileaf collimator. Many researchers have been investigated the aspects of the dosimetric characteristic of a multileaf collimator [1, 4, 5]. One of these aspects,the tongue-and-groove effect, may become a significant issue when underdosage occurs in the region of overlap of two leaf pairs of a multileaf collimator [8, 10, 12]. Results of the several investigations show that the synchronization of the leaves can avoid the tongue-and-groove effect [9,11], but this increases the total number of monitor units needed to deliver the required dose. In this work, we concentrate on a comparison of measurements of the tongue-and-groove effect and Monte Carlo simulations.

Dose calculation distributions influenced by of the tongue-and-groove effect can only accurately be predicted with the Monte Carlo method. With this method a detailed design of the multileaf collimator can be taken into account for the dose calculation. For this work the BEAM-packages [7] were used to simulate the accelerator head. In the new version of the BEAM packages there is only component module VARMLC available to model the multileaf collimator based on the design for Varian-multileaf collimator. Therefore, this component module was modified, that it can be used to simulated the Elekta-multileaf collimator.

2. Materials and Methods

2.1. The Elekta Multileaf Collimator

The Elekta multileaf collimator consists of the 80 independent leaves which are divided into two banks. The material of the leaves is tungsten alloy with a density of 18.0 g/cm^3. The Elekta multileaf collimator has curved leaf ends and a stepped design for the leaf sides. The projection of the leaf pitch in the isocentric plane is 1.0 cm, but the projection of an individual leaf is 1.1 cm. The Elekta-multileaf collimator is placed 29.8 cm below the target and has a thickness of 7.5 cm. More detailed information of the Elekta multileaf collimator can be found in the paper from Jordan et al [5] and Sykes et al [8].

The modified component module that was used to model the Elekta multileaf collimator is based on the component module VARMLC. Some modifications have been done regarding the stepped design of the leaf sides. The parameters that were required to describe the leaf are: the width of leaves (LW), the dimensions of the leaf gap (LG) and the tongue-and-groove-mechanism (WG and WT) (figure 1). All parameters are given at the top surface of multileaf collimator (ZMIN) and the leaf sides are focused to the target.

2.2. Monte Carlo simulation

The 6 MV photon beam of the Elekta-Sli plus was modeled using the BEAM program. A detailed model of this beam can be found in previous papers [2, 3]. Basic modification occurred to the multileaf collimator geometry, since the stepped design of the leaf sides was taken into account for the simulations. The treatment head was divided into two stages. The first stage consist of the target, primary collimator, low secondary filter, monitor chamber, mirror and anti-backscattering plate. The setting of these components is independent on the field size. The components of the second stage that are dependent on the setting of field, are the multileaf collimator, the backup-jaws and the lower-jaws. The multileaf collimator and the backup-jaws can move along the Y-axis and the lower-jaws along the X-axis according to Elekta convention.

In a first stage, the electron energy was modeled as a point source with 2 mm diameter at the surface of the target and has spectrum with normal distribution. This spectrum has a mean energy of 6.8 MeV and a full-width at half-maximum of 1 MeV. A trial and error method was used to obtain the mean energy, until good agreement between calculated depth dose and measured depth dose was achieved. To increase the speed of the simulation bremsstrahlung splitting and range rejection were enabled in this stage. Each bremsstrahlung photon was split into 25 photons with reduced weight. The phase space file was scored in the region below the mirror and was employed as a particle source for the second stage. This phase space file contains information of about 1.0 x 10^7 particles. From the second stage a second phase space file was generated at the front surface of phantom (90 cm below the target). The number of particles in this file depends on the field shape.

The DOSXYZ [6] code was employed to simulate the measurements which were done in a polystyrene-phantom. The second phase space file was used as input for this simulation. The voxel size was 0.2 cm perpendicular to the leaf motion direction for overlap regions and 0.5 cm for other regions, 1 cm in direction of the leaf motions and 1 cm high. The medium of voxels was set to the medium of polystyrene-phantom.

2.3. Measurement of the tongue-and-groove effect

To reproduce the tongue-and-groove effect two pairs of irregular fields were generated. All irregular fields were created by the multileaf collimator only. Figure 2 shows the leaf prescriptions of the first pair of irregular fields. The first irregular field of this pair is the half of a 20 cm x 20 cm area that was blocked with the leaves of the left leaf bank, with the leaf ends at over-travel position of 10 cm. The leaf ends of the leaves of the right leaf bank were set at 11 cm from the central axis. In the second field only the leaf positions of the left leaf bank were changed. All leaves of the left leaf bank which were opened in the first field are closed in the second field and vice versa. Therefore, the tongue-and-groove effect was measured for only one overlap region between leaves 20 and 21. Another pair of irregular fields can be seen in the figure 3. The size open area of these fields was similar to the fields of the first pair. In the first field every alternate group of two leaves from the left bank was set to cross the central axis by 10 cm and the another leaves were set 11 cm from the central axis. The second field is the complement of the leaf configuration of the first field. Using this pair of irregular fields the tongue-and-groove effect was investigated for nine overlap regions between leaves : 12-13, 14-15, 16-17, 18-19, 20-21, 22-23, 24-25, 26-27 and 28-29.

The tongue-and-groove effect was investigated by measurements with the Kodak EDR2-films in a polystyrene-Phantom. Measurements were performed at an Elekta-Sli plus with 6 MV photon beam. The films were placed at a depth of 10 cm below the phantom surface with a source-to-phantom-surface-distance of 90 cm. All films were exposed to the same number of monitor unit for each irregular subfield of the pair leaf configurations. The films were developed with a PROTEC M45 and scanned using the Vidar VXR-12 film digitizer with a pixel size of ca. 0.339 mm.

3. Results and discussions

Figure 4 shows a comparison of measured and simulated profiles for the first pair of irregular subfields. The measured and simulated profiles were normalized to the maximum dose. In this comparison an agreement within 1% was found. The statistical uncertainities of the simulated profile were kept within 1%. At the overlap region by both profiles a large deficit in dose was seen. A peak deficit of the measured profile of 27.4% with a full-width at half-maximum of 3.9 mm appeared. The peak deficit of the simulated profile happened to be 28.0% with a full-width at half-maximum of 4.6 mm. The difference between the pixel size and the voxelsize causes the difference of the full-width at half-maximum of the peak deficit.

The measured and simulated profiles from the second pair of the irregular subfields can be seen in figure 5. In this figure variation of the peak deficits at the 9 overlap regions for both profiles appeared. As for the first pair of the irregular fields, the measured and simulated profiles of the second pair were normalized to the maximum dose. In figure 5, a good agreement between measured and simulated profiles was found. Although, there are still differences at the overlap region near the edge of profile. The largest difference between measured and simulated profile is still below 5% while the statistical uncertainties of the Monte Carlo simulation are in the order of 1%.

Table 1 shows more detailed information of these variations. For the measured profile the peak deficits vary from 21.9% to 34.0% and their full-width at half-maximum from 3.3 mm to 4.6 mm. In table 1 it can be seen that the variation of the peak deficits for the measurement is independent on the position of the overlap regions. This variation may be caused by small deviations of the dimension of the leaf parameters within machining tolerance. For simulation the variation of the peak deficits shows a pattern of underdosage which depends on the location of the overlap region. The peak of deficit increases with the increment of the distance of the leaves from the central axis. The peak of deficit of the overlap region at the central beam axis is lower than the peak at the edge of the profile.

There are no obvious differences in measurements and simulations of the peak deficit and its full-width at half-maximum at the same overlap region between the two pairs of the irregular fields. This proves that the tongue and groove effect is independent on the configuration of the leaf position, but only depends on the location of the overlap region.

4. Conclusion

In this work the Monte Carlo simulation accurately reproduces the measured underdosage at overlap regions due to tongue and groove effect, if detailed informations of the leaf side design are taken into account. The differences between measured and simulated underdosage were found to be still below the maximum allowed discrepancy of measurements with film dosimetry.

Reference

1.Arnfield MR, Siebers JV, Kim JO, Qiuwen W, Keall PJ and Mohan R. A Method for determining multileaf collimator transmission and scatter for dynamic intensity modulated radiotherapy. Med Phys 2000;27:2231-41

2.Haryanto F, Fippel M, Laub W, Nüsslin F. Monte-Carlo-Simulation von Multileafkollimatoren mit gekrümmten Lamellenenden. Z Med Phys 2001; 11: 172-78

3.Haryanto F, Fippel M, Dohm O, Laub W, Nüsslin F. Investigation of photon beam output factors for conformal radiation therapy-Monte Carlo simulations and measurements. Phys Med Biol 2002; 47: N133-43

4.Huq MS, Das IJ, Steinberg T, Galvin JM. A dosimetric comparison of various multileaf collimators. Phys Med Biol 2002;47:N159-70

5.Jordan TJ, Williams PC. The design and performance characteristics of a multi-leaf collimator. Phys Med Biol 1994; 39: 231-51

6.Ma C-M, Reckwerdt P, Holmes M, Rogers DWO, Geiser B, Walters B. DOSXYZ users Manual. National Research Center of Canada Report PIRS-0509B, 1996

7.Roger DWO, Faddegon BA, Ding GX, Ma C-M, Wie J and Mackie TR .BEAM: A Monte Carlo code to simulate radiotherapy treatment units. Med Phys 1995;22: 503-24

8.Sykes RJ Williams PC. An experimental investigation of the tongue and groove effect for the Philips multileaf collimator. Phys Med Biol 1998;43:3157-3165

9.Webb S, Bortfeld T, Stein J, Convery D. The effect of stair-step leaf transmission on the tongue and groove problem in dynamic radiotherapy with a multileaf collimator. Phys. Med. Biol 1997;42:595-602

10.Webb S. Intensity Modulated Radiation Therapy, Bristol United Kingdom: Institute of physics Publishing, 2001: 99-101

11.van Santvoort JPC, Heijmen BJM. Dynamic multileaf collimator without 'tounge and groove effects'. Phys Med Biol 1996: 41 2091-105

12.Yu CX. Design considerations for the sides of multileaf collimators leaves. Phys Med Biol 1998; 43: 1335-42

Correspondence Address

Freddy Haryanto, M.Sc
Abteilung für Medizinische Physik
Radioonkologische Universitätsklinik
Hoppe-Seyler-Straße 3
D-72076 Tübingen
Germany
Telephone (+49) 7071-29-80512, Fax 7071-29-5920
E-Mail: fyharyan@med.uni-tuebingen.de

Table 1

Position of overlap region	Measurement		Simulation	
	Peak of deficit (%)	FWHM (mm)	Peak of deficit (%)	FWHM (mm)
1	34.0	4.4	33.3	4.5
2	27.3	3.9	30.5	4.0
3	21.9	3.3	26.8	4.0
4	28.1	4.1	29.2	4.0
5	27.6	4.1	30.1	4.5
6	25.0	3.8	28.2	4.0
7	25.0	3.9	29.6	4.0
8	26.5	4.1	29.2	4.5
9	28.5	4.6	30.8	4.5

Figure 1

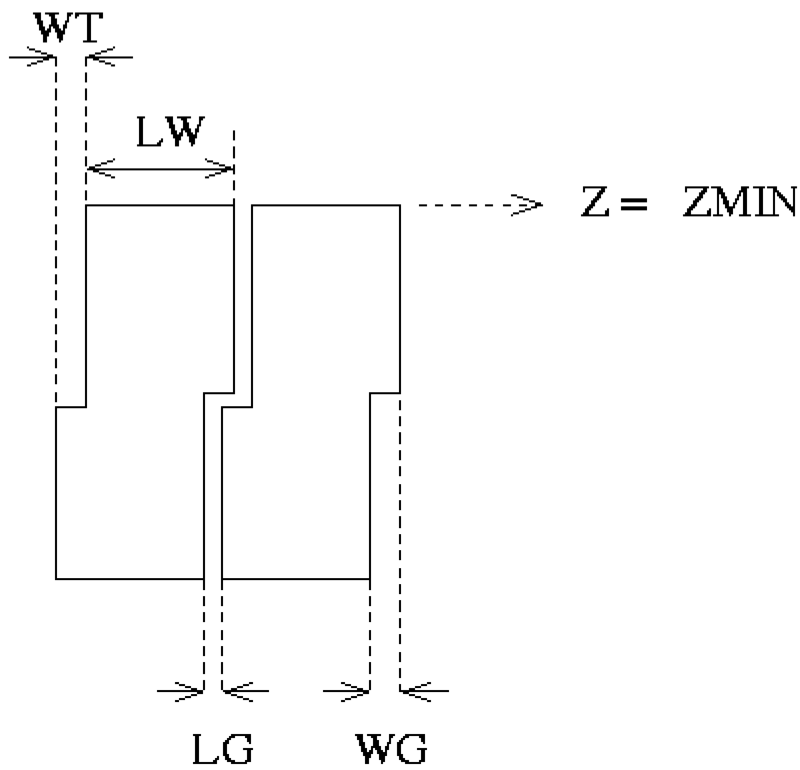

Figure 2

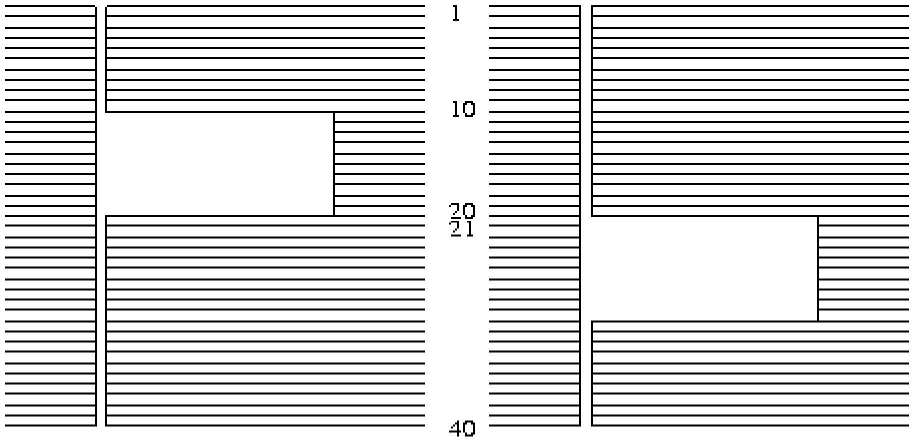

Figure 3

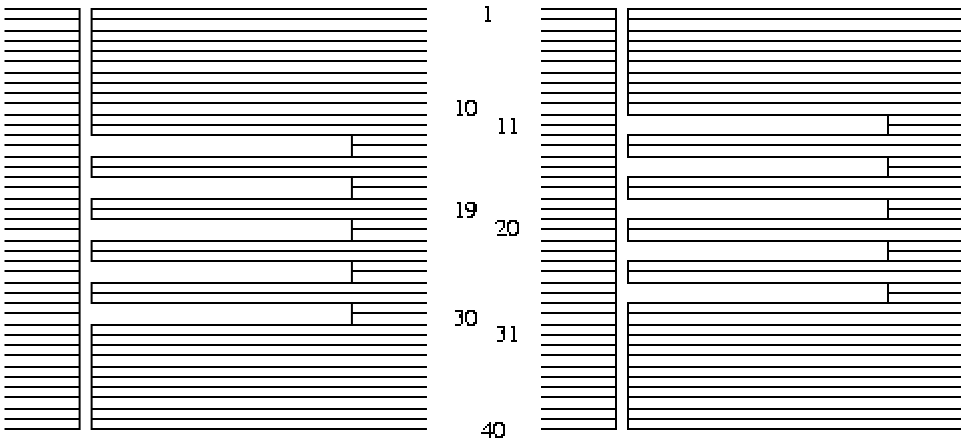

Figure 4

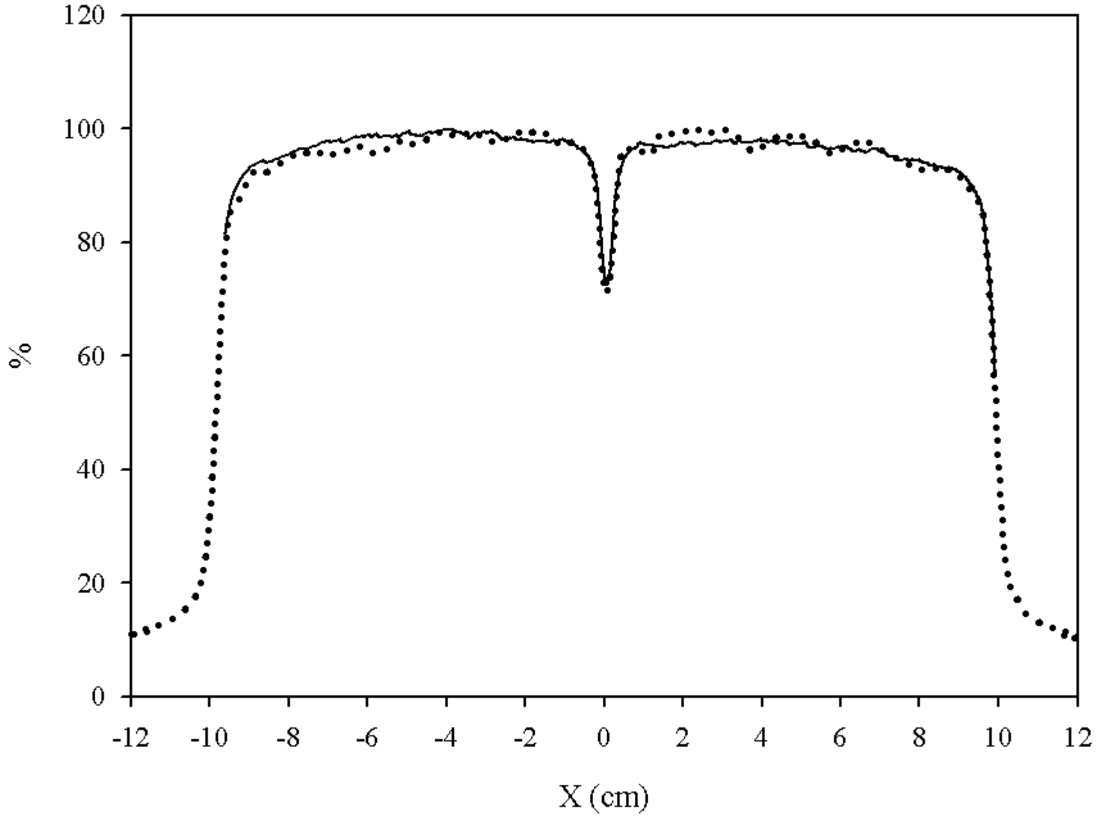

Figure 5