Strahlentherapie
und Onkologie

Radiotherapy of Prostate Cancer with Multileaf Collimators (MLCs)

Optimization of the Undulating Dose Distribution at the MLC Edge

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Background and Purpose: A technical modification for radiotherapy of prostate cancer is presented to smooth the scalloped dose pattern that occurs at treatment field edge, when a multileaf collimator (MLC) has been used.

Material and Methods: Ten patients with prostate cancer receiving postoperative, adjuvant irradiation were studied prospectively. By a three-dimensional planning system (TMS, Helax 6.1B) the irradiation was planned for an 18-MV linear accelerator (Primus 1, Siemens). The volumes of interest (VOI) were the planning target volume (PTV; the region of the prostate including the seminal vesicles), the volume of rectum (V_{rectum}) and urinary bladder ($V_{bladder}$). Two four-field techniques (0°, 90°, 180°, 270°) were planned using "beam's eye view" for setting the leaf position of the MLC. For technique A the MLC was adapted to the PTV using a 0° collimator angle for the lateral fields. For technique B the collimator angle of the lateral fields was optimized to compensate the cascade field shape. Dose-volume histograms of PTV, V_{rectum} and $V_{bladder}$ were analyzed. The dose was prescribed for the reference point according to ICRU 50. Film dosimetry was used to show the dose pattern at the field edge produced by the two techniques.

Results: Dose to PTV did not differ between technique A and B. Median dose to V_{rectum} was 82.6% for technique A and 77.3% for technique B ($p < 0.001$). Technique A irradiates a larger V_{rectum} than technique B being significant for all isodose levels tested. Median dose to $V_{bladder}$ did not differ for technique A and B ($p > 0.05$).

Conclusion: The presented technical modification is an effective method to blur the staggered dose distribution that results, when the MLC is conventionally stepped to adapt to the dorsal, irregular PTV border in irradiation of prostate. Especially for irradiation to escalated dose levels, this modification may reduce the dose to the rectum and thus the rectal side effects in comparison to the conventional MLC fields.

Key Words: Prostate cancer · Irradiation technique · Multileaf collimator

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Radiotherapie des Prostatakarzinoms unter Verwendung des Multileaf-Kollimators (MLC). Optimierung der stufenartigen Dosisverteilung am MLC-Rand

Hintergrund und Ziel: Eine Modifikation der Bestrahlungstechnik beim Prostatakarzinom wird vorgestellt, die den mehrstufigen Dosisverlauf am Feldrand ausgleicht, wie er bei Verwendung eines Multileaf-Kollimators (MLC) entsteht.

Material und Methodik: Zehn Patienten wurden in die Analyse einbezogen. Mittels eines dreidimensionalen Bestrahlungsplanungssystems (Helax TMS 6.1B) wurden die Bestrahlungstechniken für einen 18-MV-Linearbeschleuniger (Primus 1, Siemens) berechnet. Als „volumes of interest" (VOI) wurden das Planungszielvolumen (PTV; Prostataregion inkl. Samenblasen) sowie das Volumen von Rektum (V_{rectum}) und Harnblase ($V_{bladder}$) definiert. Zwei Vierfeldertechniken (Gantry: 0°, 90°, 180°, 270°) wurden unter Verwendung des „beam's eye view" geplant. Bei Technik A wurde der MLC in jedem Feld bei einem Kollimatorwinkel von 0° an das PTV angepasst, bei Technik B wurde der Kollimatorwinkel der seitlichen Felder so optimiert, dass sich die in den seitlichen Feldern entstehenden Stufen gegenseitig ausglichen. Die Dosis-Volumen-Histogramme von PTV, V_{rectum} und $V_{bladder}$ wurden ausgewertet. Die Dosisangabe bezieht sich auf den Referenzpunkt gemäß ICRU 50. Durch Filmdosimetrie wurde der Dosisverlauf am Feldrand bei beiden Techniken überprüft.

Ergebnisse: Die Dosis im PTV unterschied sich bei Technik A und B nicht. Die mediane Dosis in V_{rectum} betrug 82,6% für Technik A und 77,3% für Technik B ($p < 0{,}001$). Die Werte für V_{rectum} waren in allen untersuchten Dosisbereichen für Technik A größer als für Technik B. Die mediane Dosis in $V_{bladder}$ unterschied sich bei beiden Techniken nicht ($p > 0{,}05$).

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Schlussfolgerung: Die vorgestellte Modifikation ist eine einfache und effektive Methode zum Ausgleich der stufigen Feldränder und Dosisverläufe, wie sie bei der Verwendung von MLC entstehen. Bei der Bestrahlung des Prostatakarzinoms ist dadurch eine Dosisreduktion im Bereich des Rektums mit evtl. reduzierten Nebenwirkungen möglich.

Schlüsselwörter: Prostatakarzinom · Bestrahlungstechnik · Multileaf-Kollimator

Introduction

Multileaf collimators (MLCs) allow the radiation beam to be irregularly shaped to conform to tumor volumes without the use of individually shaped alloy blocks, whose production, daily handling and storage are labor-intensive and resource-consuming [11]. On the other hand, the well-defined edge obtained by individual shielding blocks is not copied by MLCs. The accuracy with which the MLC leaves fit the planning target volume (PTV) is influenced by the leaf width being commonly 10 mm at isocenter. Therefore, the stepped approximation of the MLC to an irregular PTV results in an undulating dose pattern at the border of the beams. When the border of the PTV is smooth and in close vicinity to a critical structure, the undulating dose pattern can be a disadvantage. This situation is found in radiotherapy of prostate cancer. In a recent study, Bedford et al. reported that the dose to the rectum increased significantly when changing from conformal blocks to MLCs [2].

The present study aims to optimize the MLC leaf fitting of a four-field irradiation technique for prostate cancer and thereby to reduce the dose to the rectum.

Material and Methods

Ten consecutive patients receiving postoperative radiotherapy because of prostate cancer were studied. The irradiation was indicated because of a T3 status. All patients were scanned using computed tomography (CT) at 5-mm intervals from lumbar vertebra 5 to lesser trochanter. The patients were instructed to undergo CT scan with full bladder. Following volumes of interest (VOI) were defined in each axial CT slice:

- the PTV, encompassing the region of prostate and seminal vesicles.
- the volume of the rectum (V_{rectum}) within the longitudinal PTV extension plus 1 cm cranially and caudally. As usually used in literature [2], rectal volume and not rectal wall was defined as organ at risk.
- the volume of the bladder ($V_{bladder}$).

Treatment planning was performed using a three-dimensional (3-D) planning system (Helax, TMS 6.1B) for 18-MV photons to be delivered by a Primus 1 (Siemens) linear accelerator. The grid size of dose matrix geometry was 1 mm for dose calculation.

A four-field box technique was used consisting of gantry angles at 0°, 90°, 180°, and 270° with the beam weights in the ratio 1.2 : 1.4 : 1.0 : 1.4 at the isocenter. Beam's eye view was used for adjusting the leaf (width 1 cm in isocenter) positions for all fields.

- For technique A the collimator angles for all fields were 0°.
- For technique B the collimator angle of the 90°-field was individually chosen to optimize the adaptation of leaves to the dorsal border of PTV. The collimator angle of the 270°-field worked in opposite direction to compensate the cascade dorsal field border of the 90°-field.

Figures 1 and 2 schematically show the principle of technique A and B.

The dose-volume histograms (DVHs) of VOI were calculated. The DVH of V_{rectum} and $V_{bladder}$ was analyzed at the following isodose levels: 90%, 80%, 60%, and 40%.

A radiographic film was used to show the dose pattern produced by technique A and B (two fields: 90°, 270° gantry angle). Film exposures were carried out using a laser scanner, and film densities were converted to dose (IBA Omni Pro-Accept 6.0A, Kodak X-OmatV, perspex phantom with 10 cm depth, 18-MV photon). Isodose distributions were plotted with each distribution normalized to 100% at the central axis (Figure 3). For both techniques the 95% isodose was required to include the PTV. Effective penumbra widths corresponding to the area between PTV and the 90–40% isodose lines were measured for each film.

For statistical analysis STATISTICA Kernel-Version 5.5 was used. Differences were tested for significance using the t-test.

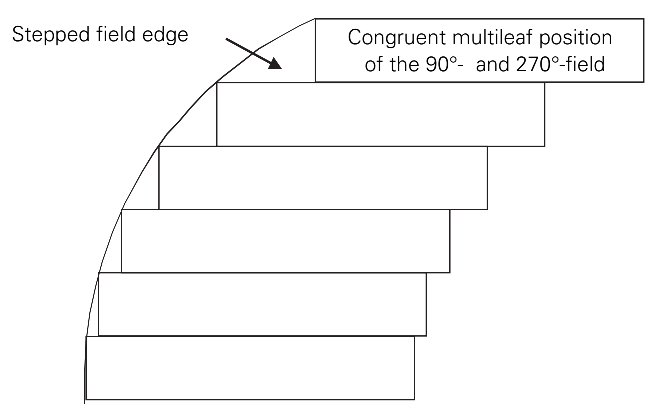

Figure 1. Schematic representation of the conventional MLC technique. The congruent collimator position of the opposing fields results in a stepped field edge.

Abbildung 1. Schematische Darstellung der konventionellen MLC-Technik. Die gleichsinnige Kollimatorposition der Gegenfelder führt zu einem stufenförmigen Feldrand.

Results

Film Measurement

Field edge smoothing for technique B introduces two improvements to the penumbra. The scalloped edge effect in all isodose lines is smoothed and the effective penumbra width, defined as the area between PTV and isodose lines, is reduced (Figure 3). Table 1 lists the effective penumbra width for the different techniques. The area between PTV and the isodose lines was reduced by 11% (40% isodose line) to 23% (90% isodose line).

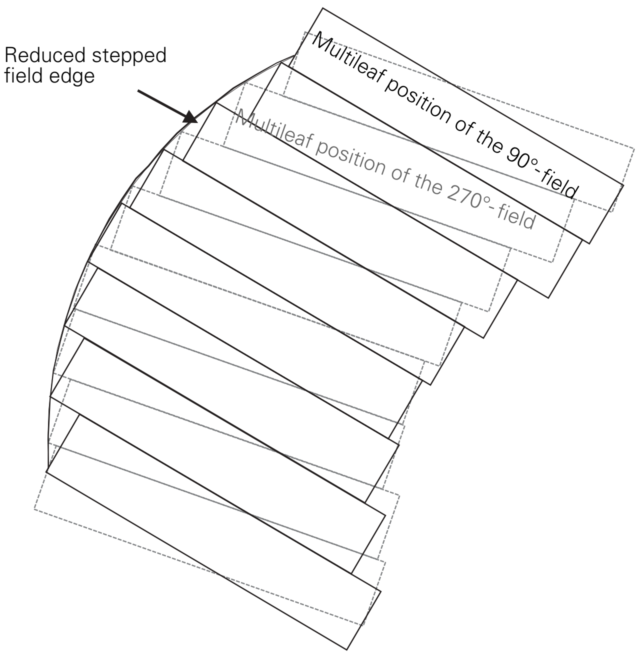

Figure 2. Schematic representation of the modified MLC technique. The individualized collimator position of the opposing fields results in a reduced stepped field edge.

Abbildung 2. Schematische Darstellung der modifizierten MLC-Technik. Die individuell angepasste Kollimatorposition der Gegenfelder führt zu einem Ausgleich des stufenförmigen Feldrandes.

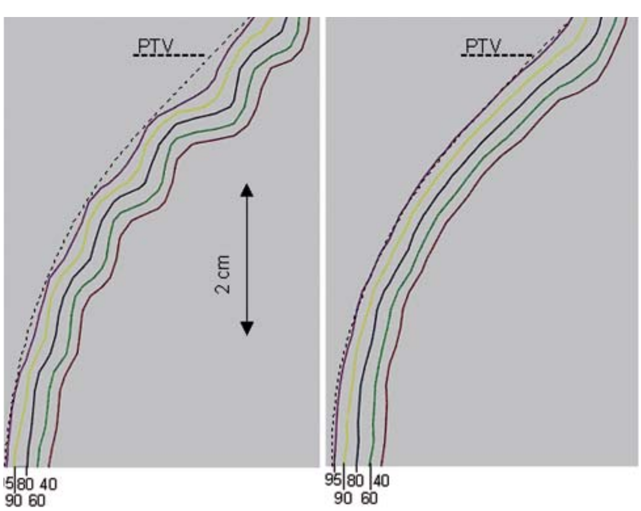

Figure 3. Film dosimetry: side-by-side comparison of 95–40% isodose lines in penumbra region of opposing fields by technique A and B.

Abbildung 3. Filmdosimetrie: Gegenüberstellung der 95–40%-Isodosenlinien im Halbschattenbereich des Feldrandes bei Technik A und B.

Dose-Volume Histograms

Median PTV was 272 cm^3 (range: 164–345; standard deviation [SD]: 52.7). Technique B provides comparable PTV coverage to technique A. Median dose to PTV was 100.5% (98.8–100.6; SD 0.74) for technique A and 100.5% (98.7–101.2; SD 0.75) for technique B ($p > 0.05$).

Median dose to V_{rectum} was 82.6% (63.7–95.1; SD 11.1) for technique A and 77.3% (75.8–91.1; SD 10.6) for technique B ($p < 0.001$). The mean dose reduction by technique B amounted to 5.3% (0.1–8.8; SD 2.7). Technique A irradiates a larger V_{rectum} than technique B, being significant for all tested isodose levels tested (90%/80%/60%/40% isodose; Table 2).

Contrary to this, neither median dose to the bladder nor irradiated $V_{bladder}$ at any dose level differed for technique A and B. Median dose to $V_{bladder}$ was 77.7% (45.8–98.2; SD 18.5) for technique A and 77.9% (45.7–98.0; SD 18.4) for technique B.

Discussion

Although inverse treatment planning and intensity-modulated radiotherapy will be more and more used for radiotherapy of prostate cancer in the future [4, 17], most patients are irradi-

Table 1. Film dosimetry: effective penumbra width measured as area between planning target volume and isodose lines.

Tabelle 1. Filmdosimetrie: effektive Größe des Halbschattens, gemessen als Fläche zwischen dem Planungszielvolumen und den Isodosenlinien.

	Technique A Area (cm^2)	Technique B Area (cm^2)
90% isodose	1.63	1.25
80% isodose	2.64	2.24
60% isodose	3.93	3.48
40% isodose	5.08	4.54

Table 2. Volume of rectum within tested isodose levels in percent (mean, standard deviation [SD]).

Tabelle 2. Rektumvolumen innerhalb der untersuchten Isodosenbereiche in Prozent (Mittelwert, Standardabweichung [SD]).

	Technique A		Technique B		
	Mean	SD	Mean	SD	p-value
90% isodose	43.9	8.3	41.4	6.8	p < 0.02
80% isodose	51.6	7.5	48.5	6.5	p < 0.01
60% isodose	68.8	12.1	62.3	7.7	p < 0.04
40% isodose	98.5	1.9	97.7	2.0	p < 0.01

ated today by forward planned 3-D conformal radiotherapy [5, 10, 13, 15, 16]. In the past, MLC systems replaced conventional blocks in 3-D conformal radiotherapy. The MLC allows the radiation beam to be irregularly shaped to conform to tumor volumes without the use of cerrobend blocks [9, 11]. Helyer & Heisig reported a time reduction of 19–48% for parallel opposed beams and 6–44% for conformal isocentric beams by the change from alloy blocks to MLCs [11]. Additionally, LoSasso & Kutcher described a higher accuracy of MLCs, because lead alloy blocking contains lower precision with positioning errors due to block misalignment [12]. However, the well-defined edge obtained with divergent blocking is not duplicated with the MLC. Since the MLC leaf width is commonly 10 mm at isocenter, the treatment fields do not exactly follow the beam's eye view of the PTV, but instead provide a stepped approximation to the PTV shape [1]. When the border of the PTV falls in close proximity to a critical structure also having a relatively smooth edge, the undulating dose pattern can be a disadvantage.

Some authors suggest that the importance of this effect is reduced by the daily setup variations and the organ mobility [2, 6]. From our point of view it is not admissible to postulate that one disadvantage (stepped dose pattern) is compensated by another (daily setup error). On the contrary, it may be assumed that at least in unfavorable circumstances disadvantages have to be added up.

Because of stepped dose pattern Galvin et al. estimate that in 19% of the clinical static fields the field shaping could not be adequately accomplished using MLCs [8]. The most critical situation is, when the normal tissue dose is close to the tolerance with cerrobend blocks [3]. Further increase in the volume of or the dose to the organ at risk irradiated as a result of MLCs may induce a clinically unacceptable situation. A typical example is the treatment of prostate cancer. The rectal wall is normally near its tolerance dose, when cerrobend blocks are used. If the blocks are replaced with MLCs, dose to some segments of the rectal wall may increase resulting in higher side effects. Bedford et al. compared an MLC with conformal blocks for delivering the boost phase of dose-escalated conformal prostate radiotherapy [2]. The PTV coverage was comparable for the block and the MLC technique. However, the MLC technique irradiated a larger V_{rectum} both to low dose (50% isodose) and to high dose (90% isodose). The source of this effect is again the undulating dose pattern at the field edge. There are a number of solutions for the problem of dose scalloping at a stepped MLC edge. It is possible to rotate the collimator system to decrease the amount of stepping at the border. Smith et al. reported that the number of unfavorable cases was reduced from 25% to 10% when rotation was used [14]. Although the MLC fitting is closer to the PTV by this technical modification, the width of the dose pattern steps is still 1 cm because of the 1-cm width of the leaves. Galvin et al. described another procedure to smooth the scalloping effect of MLCs and to reduce the effective penumbra [7]. They divided the treatment field into a number of subfields in which the MLC is shifted by a fraction of leaf width and adjusted to redefine the field edge in relation to the new position of the treatment volume border. This leads to a reduction of the effective leaf width and thus to a reduction of the undulating dose pattern. Although theoretically an acceptable solution, this procedure with three or four different central axes per field seems not be suitable for daily clinical use. The treatment technique demonstrated in this paper conflates the advantages of the both technical modifications described above. First, by individualizing the collimator angle the MLC can better be adapted to the border of the PTV. The second effect is that the collimator angle of the 270°-field is different from and not exactly correspondent to the 90°-field. As a result of this, the steps of the MLC field edges of both fields are shifted and the effective leaf width is reduced, both resulting in a blurred dose pattern. In our clinical study we could significantly reduce the V_{rectum} within the high-dose (90% isodose) and the low-dose (40% isodose) regions for a four-field-technique. Since it is an isocenter technique and treatment time is not extended compared to the conventional MLC technique, this technique is practicable for daily routine irradiation of patients with prostate cancer. Especially for irradiation of the prostate to escalated dose levels, the presented MLC field modification may reduce the dose to the rectum and thus the rectal side effects in comparison to conventional MLC fields.

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