

OPTIMIZATION OF COLLIMATOR PARAMETERS TO REDUCE RECTAL DOSE IN INTENSITY-MODULATED PROSTATE TREATMENT PLANNING

JULIE CHAPEK, C.M.D., MATT TOBLER, C.M.D., BEAU J. TOY, M.D.,
CHRISTOPHER M. LEE, M.D., DENNIS D. LEAVITT, PH.D.
Huntsman Cancer Hospital, University of Utah Health Science Center, Salt Lake City, UT
Radiation Oncology Centers of Las Vegas, Las Vegas, NV

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Abstract—The inability to avoid rectal wall irradiation has been a limiting factor in prostate cancer treatment planning. Treatment planners must not only consider the maximum dose that the rectum receives throughout a course of treatment, but also the dose that any volume of the rectum receives. As treatment planning techniques have evolved and prescription doses have escalated, limitations of rectal dose have remained an area of focus. External pelvic immobilization devices have been incorporated to aid in daily reproducibility and lessen concern for daily patient motion. Internal immobilization devices (such as the intrarectal balloon) and visualization techniques (including daily ultrasound or placement of fiducial markers) have been utilized to reduce the uncertainty of intrafractional prostate positional variation, thus allowing for minimization of treatment volumes. Despite these efforts, prostate volumes continue to abut portions of the rectum, and the necessary volume expansions continue to include portions of the anterior rectal wall within high-dose regions. The addition of collimator parameter optimization (both collimator angle and primary jaw settings) to intensity-modulated radiotherapy (IMRT) allows greater rectal sparing compared to the use of IMRT alone. We use multiple patient examples to illustrate the positive effects seen when utilizing collimator parameter optimization in conjunction with IMRT to further reduce rectal doses. © 2005 American Association of Medical Dosimetrists.

Key Words: Optimization, Collimator parameters, Prostate radiation therapy, IMRT.

INTRODUCTION

Developments in treatment planning systems have allowed a shift from conventional, nonconformal radiation therapy to highly conformal 3-dimensional (3D) planning and intensity-modulated radiation therapy (IMRT). As dose is made to be more conformal to the planning target volume (PTV), there can be a reduction of dose delivered to normal tissues. Improved dose conformality allows for the consideration of prescription dose escalation. In turn, the ability to safely achieve higher doses has led to important milestones in the treatment of prostate cancer, where data support that dose escalation in the treatment of prostate cancer results in significantly improved prostate-specific antigen (PSA) relapse-free survival in patients with intermediate and unfavorable prognosis.¹

Along with dose escalation, it is essential to minimize the volume of normal tissues that are treated to higher doses to be able to achieve a higher therapeutic ratio. In treating the prostate, the main limiting factor is dose delivered to the rectum. This dose must not only be considered as a maximum point dose, but the entire dose-volume histogram (DVH) must be evaluated. When treating patients to doses of 70.2–75.6 Gy, it has been reported that rectal bleeding correlated to significant

increase in irradiated rectal volume.² In a study by Wachter *et al.*, it was reported that grade 2 late rectal complications occurred in patients who had more than 57% of the rectum irradiated to 60 Gy.³ Boersma *et al.* also showed, through analysis of irradiated volumes, that there was a significant increase in the incidence of severe rectal bleeding in patients where more than 40–50% of the rectal wall received at least 65 Gy.⁴ In their preliminary report of a randomized 3D-CRT (conformal radiation therapy) dose escalation trial, Storey *et al.* reported that patients with > 25% of rectal volume irradiated to \geq 70 Gy developed grade 2 or higher complications.⁵ Over a longer follow-up period, Huang *et al.* found that dose and volume were continuously interrelated variables with a significant volume effect observed at rectal doses of 60, 70, 75.6, and 78 Gy, with the risk of rectal complications increasing exponentially with increased irradiated volume.⁶ This dose-volume relationship becomes increasingly significant as dose escalation occurs. Arm 2 of the current Radiation Therapy Oncology Group (RTOG) protocol for prostate cancer (#0126) recommends prostate prescription doses of 79.2 Gy (with dose inhomogeneity \leq 7%) and provides strict guidelines for the evaluation of the DVH. With these escalated prescription doses, the need to reduce dose to rectal volumes becomes more critical. In this RTOG protocol, it is recommended that less than 15% of the rectal volume receive 75 Gy, less than 25% receive 70 Gy, less than

Reprint requests to: J. Chapek, C.M.D., Department of Radiation Oncology, Huntsman Cancer Hospital, 1950 Circle of Hope, Salt Lake City, UT 84112-5560. E-mail: Julie.chapek@hci.utah.edu

35% receive 65 Gy, and that no more than 50% volume receive more than 60 Gy.

In an effort to reduce the volume of rectal wall, irradiated innovative techniques have been employed to better localize or stabilize the target volume at each treatment. These include intrarectal balloons, daily ultrasound, and fiducial markers implanted in the prostate. Patel *et al.* have reported on the use of a rectal balloon catheter resulting in a significant decrease in the volume of rectal wall receiving high dose (> 60 Gy).⁷ Localizing the prostate using transabdominal ultrasound on a daily basis provides a rapid way of adjusting fields to match the target volume prior to each treatment.^{8,9} Many authors have evaluated the feasibility of gold-seed fiducial markers implanted into the prostate and utilized daily to localize the prostate prior to treatment.^{10–13} Better volume stabilization and/or daily volume localization will lead to increased confidence in daily treatment reproducibility. As a result of this increased confidence, physicians may decrease the amount of expansion they require around the clinical target volumes (CTVs) to create the planning target volumes (PTVs).

Despite gains made in daily localization and the possible reduction in size of PTVs, prostate volumes directly abut portions of the rectum and when these volumes are expanded to create PTVs, they may actually include portions of the rectum in the high-dose regions. It has been shown that utilizing 3D-conformal planning or IMRT reduces rectal and bladder doses and therefore improves the risk-to-benefit ratio.¹⁴ These planning techniques have also led to clinically acceptable escalation of prescription doses for prostate cancer treatment. It is therefore essential for dosimetrists to continually investigate techniques that will result in the further reduction of doses to the rectum. In this study, we examined the effect of adjusting collimator parameters. Primary collimator settings and collimator angles were adjusted relative to the geometry of the rectum, making these parameters more conformal to the rectum. We evaluated whether the adjustments of these parameters, when used in conjunction with IMRT planning, can result in a reduction of dose delivered to the rectum.

METHOD

Patient selection

Three patients were selected for this study. Patients were chosen based on the angle of the rectum compared to a neutral collimator angle (*i.e.*, 0° , 90° , 180° or 270°). It was felt that a large angle between the rectum and the neutral collimator angle would be the condition when the maximum amount of rectum would be unshielded. This is partially due to the stair-stepped appearance of the multileaf collimator (MLC) leaves along the length of the rectum as they create the field shape required to cover the PTV (Fig. 1a). This figure also shows that there is a large volume of rectum that is shielded only by the MLC

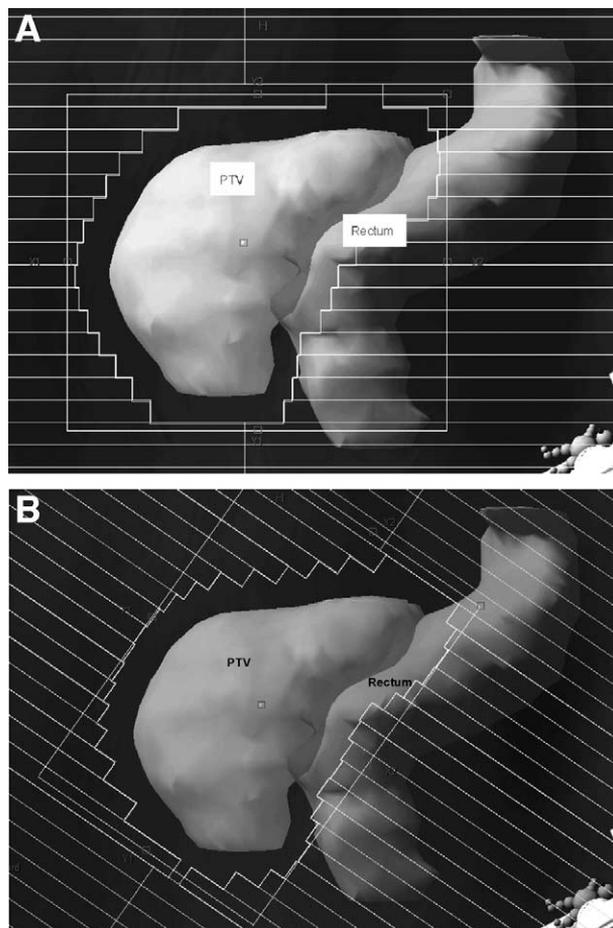


Fig. 1. Currently, the standard IMRT collimator setup procedure utilizes no optimization of collimator parameters. (A) Collimator angle is set at a neutral angle (180°) and the primary collimators are set to the pre-set default settings outside the maximum MLC aperture. (B) Full optimization of the collimator parameters utilizes optimization of both collimator angle to match the angle of the rectum and of the primary collimators to bring jaws in as close as possible to the edge of the MLC aperture.

leaves and not the primary collimators. This underlying rectal volume would receive dose during treatment in the form of transmission through the MLC leaves (which is on the order of 2.4%).

Definition of rectum and rectal wall

For the purpose of our study, the rectum was contoured from the inferior portion of the ischial tuberosities up to the superior aspect of the rectosigmoid flexure. The rectal wall was defined as a 2-mm-thick wall extending from 2.5 mm inferior to the most inferior aspect of PTV to 2.5 mm superior to the most superior aspect of the PTV. The rectal wall was evaluated in this study, because it extended such a small distance beyond the PTV; therefore; this volume benefited most from the study, resulting in greater reduction to rectal wall dose.

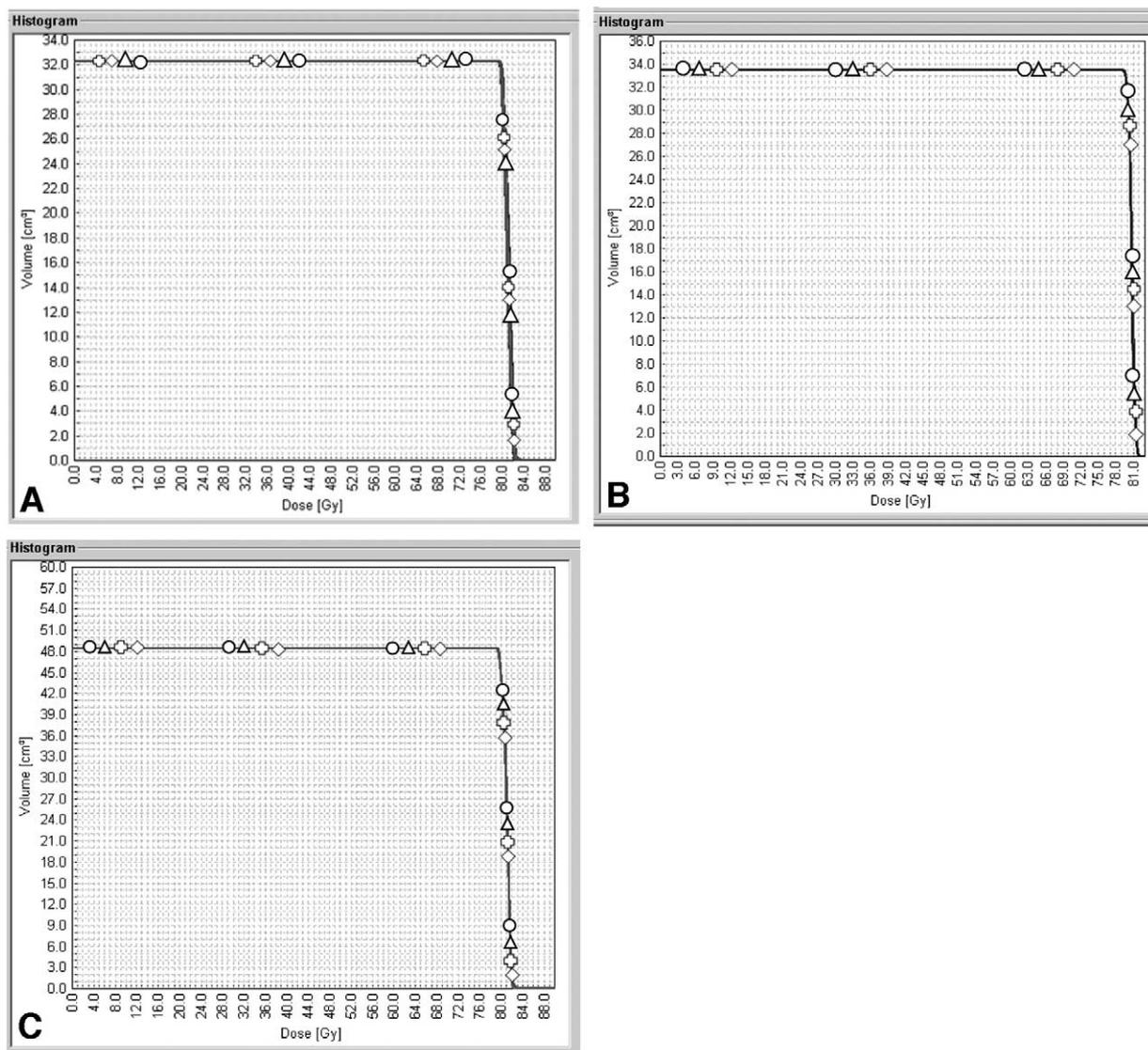


Fig. 2. DVHs for the CTV of (A) patient A, (B) patient B, and (C) patient C show that no optimization (diamond), primary collimator setting optimization only (triangle), collimator angle optimization only (circle), and the fully optimized collimator parameter (cross) plan delivered comparable results. Plans done with 1-cm MLC leaves.

Definition of target volumes

In each case, the CTV was defined as the prostate and proximal 1 cm of seminal vesicles without a margin. The PTV was an expansion of 1 cm beyond the CTV in all directions except posterior, where expansion was 6 mm. The dosimetric coverage of the target volumes was defined as the 100% isodose line to cover the entire CTV and the 95% isodose line to cover the entire PTV.

Evaluated variables

For each patient studied the following variables were applied:

1. Collimator angle set at a neutral angle of 180°. Primary collimators were set to preset default of 3 mm (in Y direction) and 5 mm (in X direction) outside the

MLC leaves. (Fig. 1a). This is currently the most commonly accepted collimator parameter setup procedure.

2. Primary collimator settings optimized to bring the jaws in as close as possible to the edge of MLCs without impinging on the treatment field. This will reduce the amount of extra dose delivered as a result of transmission through the MLC leaves, as the primary collimators shield as much of the MLC area as possible.
3. Collimator angle optimized so that the angle of the collimator followed a best fit of the angle of the rectum. Primary collimator settings were allowed to follow the preset default defined above in point no. 1. Collimator angle was determined by visual

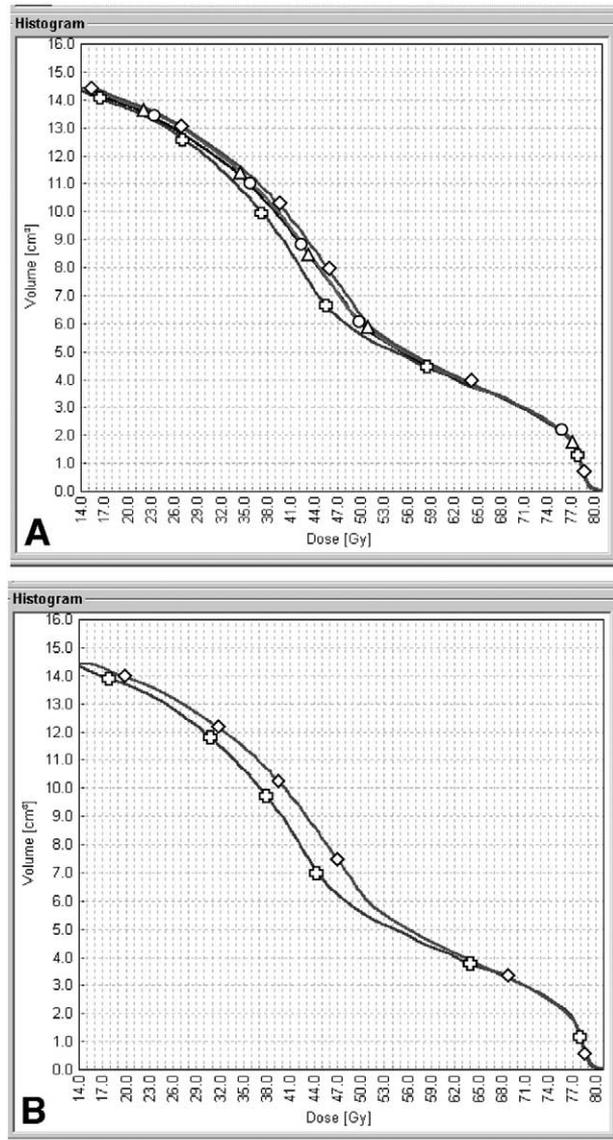


Fig. 3. Patient A. (A) DVH for rectal wall shows that the non-optimized plan (diamond) delivers the highest dose to the rectal wall compared to the plans with primary collimators optimized (triangle), collimator angle optimized (circle), and the fully optimized collimator and primary collimator positions (cross). (B) DVH comparison for the rectal wall showing only the non-optimized results (diamond) and the fully optimized collimator and primary collimator positions results (cross) illustrate a dramatic improvement in rectal sparing with the fully optimized technique. Plans done with 1-cm MLC leaves.

adjustment until it best followed the slope of the rectum. This resulted in a minimized stair-step effect of the MLCs, as the angle of incidence of the leaves was more conformal to the angle of the rectum. This more conformal collimator angle also resulted in the primary collimators shielding an increased area of the MLCs, therefore reducing transmission through the leaves to the patient.

- Collimator angle and primary collimator settings were fully optimized as described in point nos. 2 and 3 above, to achieve the maximum amount of shielding on the rectum while still covering the PTV (Fig. 1b).

Plans were evaluated using the Varian Eclipse treatment planning system. (Varian Medical Systems, Palo Alto, CA).

It was essential to ensure that all plans were executed in a similar manner. Only the evaluated individual variables were altered for each plan. Due to the computer algorithm applied within the planning system as it performs an optimization on an IMRT plan, it is never possible to achieve an identical optimization on the same patient with the same plan. To reduce this variation to a minimum, an initial plan was run in which both collimator angle and primary collimator position were fully optimized. This plan was the first one to be executed because we felt that this situation of fully optimized collimator parameters would give the best end results. In the IMRT optimization process for this plan, the optimization parameters (dose constraints and priority settings) were determined. This developed optimization parameter set was saved as an optimal constraint template. Fluence patterns were then deleted from the initial plan and the plan was re-optimized and calculated using the saved optimal constraint template. The IMRT optimization process was allowed to continue until no further improvements were registered in the planning system with each additional iteration. In the same manner, this constraint template was then applied to all subsequent planning situations.

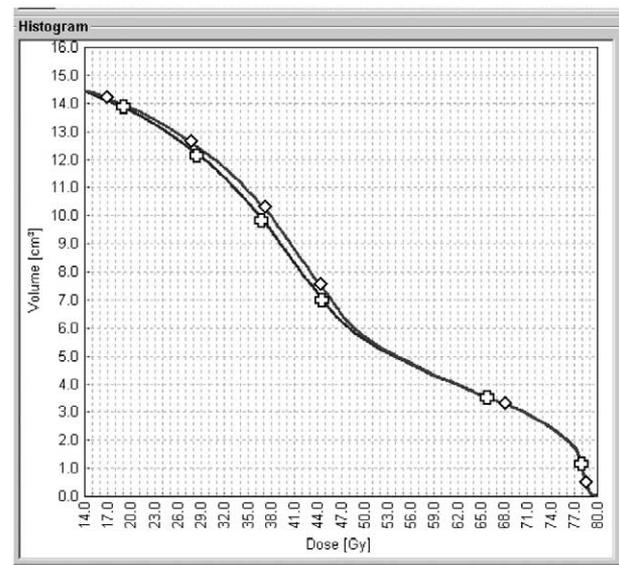


Fig. 4. Patient A. The DVH for the rectal wall showing results for the non-optimized collimator parameters (diamond) and the fully optimized collimator angle and primary collimator settings (cross) with the 0.5-cm MLC leaves. Results show an improvement in rectal sparing with the fully optimized plan.

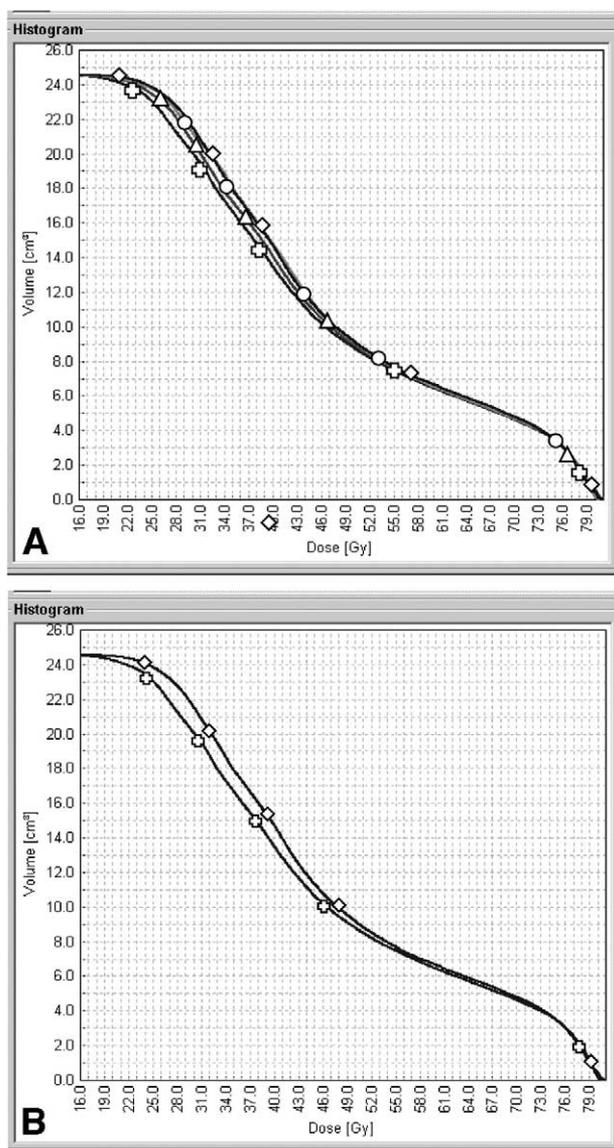


Fig. 5. Patient B. (A) DVH for the rectal wall again shows that the non-optimized plan (diamond) delivers the highest dose to the rectal wall compared to the plans with primary collimators optimized (triangle), collimator angle optimized (circle), and the fully optimized collimator and primary collimator positions (cross). (B) DVH comparison for the rectal wall showing only the non-optimized results (diamond) and the fully optimized collimator and primary collimator positions results (cross) illustrates, as for patient A, the reduction in rectal dose when utilizing the fully optimized plan. Plans done with 1-cm MLC leaves.

Each variable was evaluated using geometrically identical 7 field plans. As per arm 2 of RTOG protocol for prostate cancer (#0126), a prescription dose of 79.2 Gy was used for all plans in this study. Within our department, we utilize linear accelerators equipped with either 1-cm leaves or 0.5-cm leaves. It was decided that all plans would be evaluated using both the 1- and

0.5-cm MLC leaves, and the resulting DVHs would be compared.

RESULTS

DVH evaluation of doses delivered to the CTV revealed that for all 3 patient cases, equivalent volume coverage was achieved for each planning situation. Hence, the application of the studied variables in no way compromised CTV coverage (Fig. 2a–c). Evaluation of the DVH for the rectal wall, however, shows gains in rectal sparing as a result of the optimization of the collimator parameters. For patient A, Fig. 3a illustrates that the non-optimized technique (currently the most commonly used parameter setup procedure) achieved the worst result for dose delivered to the rectal wall. Optimization of the primary collimator setting alone or optimization of the collimator angle alone achieved results that were a slight improvement in rectal wall dose over no optimization. Combination of both primary collimator setting and collimator angle optimization achieved results that were a dramatic improvement over the other techniques evaluated. This improvement was also noted with the fully optimized 0.5-cm MLC leaves, although the improvement in rectal wall dose was not as dramatic as that achieved with the 1-cm leaves (Fig. 4).

For both patients A and B, the angle of the rectum deviated from the neutral collimator angle by approximately 14°. DVHs for patient B show results that are similar to those of patient A (Fig. 5a and 5b, Fig. 6). For the fully optimized technique, results show a greater reduction in rectal wall dose compared to the partially

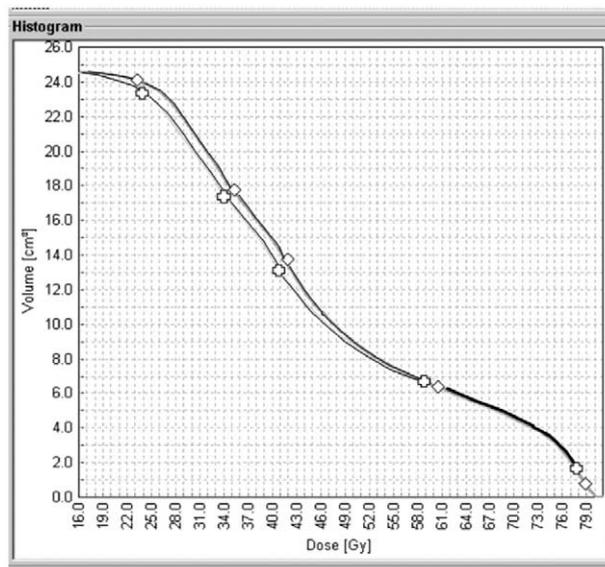


Fig. 6. Patient B. The DVH for the rectal wall showing results for the non-optimized collimator parameters (diamond) and the fully optimized collimator angle and primary collimator settings (cross) with the 0.5-cm MLC leaves. Results show an improvement in rectal sparing with the fully optimized plan.

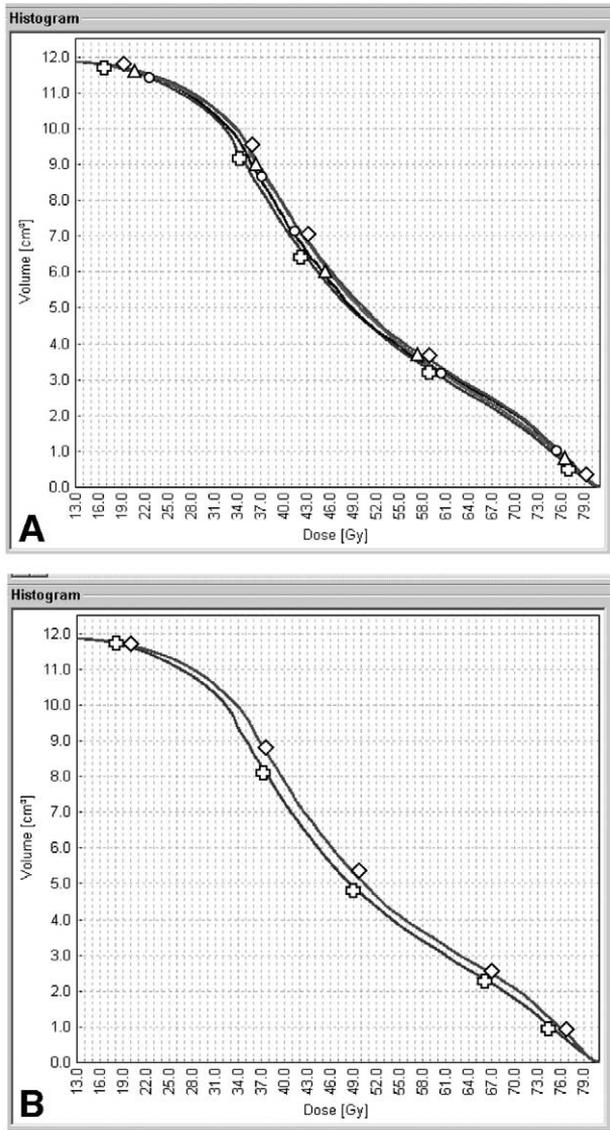


Fig. 7. Patient C. (A) DVH for the rectal wall shows that the non-optimized (diamond) plan delivers the highest dose to the rectal wall compared to the plans with primary collimators optimized (triangle), collimator angle optimized (circle), and the fully optimized collimator and primary collimator (cross) positions. (B) DVH comparison for the rectal wall showing only the non-optimized results (diamond) and the fully optimized collimator and primary collimator positions results (cross) again show the benefit gained in reducing rectal dose in fully optimized plan. The separation of the DVH curves for this patient is greater than that for patients A or B. Reductions of rectal wall dose extend well into the high-dose regions for the curve. Plans done with 1-cm MLC leaves.

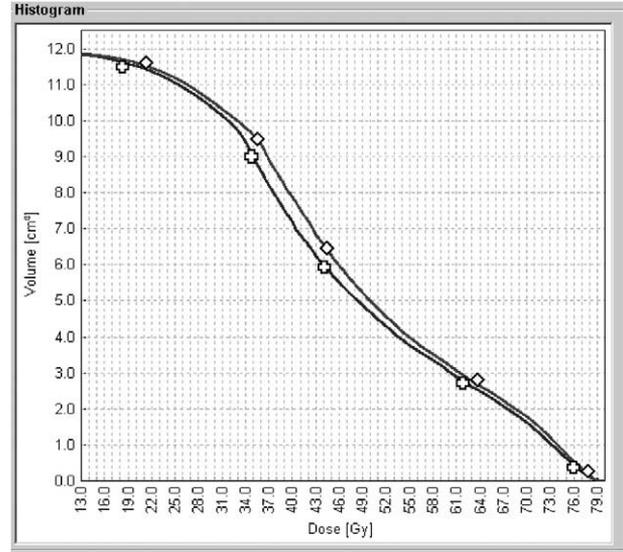


Fig. 8. Patient C. The DVH for the rectal wall showing results for the non-optimized collimator parameters (diamond) and the fully optimized collimator angle and primary collimator settings (cross) with the 0.5-cm leaves. Results show an improvement in rectal sparing with the fully optimized plan.

optimized situations, even with this small amount of collimator angle introduced into the plan. For patient A, the 0.5-cm MLC leaves also show the greatest reduction in rectal wall dose when the fully optimized collimator parameters were applied to patient B.

The reduction in rectal wall dose is most impressive for patient C. The anatomy of this patient was such that the rectal wall angle deviated from the neutral collimator angle by approximately 24°. This large angle allowed for a large change in both shape and conformity (as a result of the collimator angle optimization) and in MLC transmission (due to primary collimator optimization). DVHs for patient C show reductions in rectal wall dose that extend well into the high-dose regions of the curve with the fully optimized collimator parameters for both the 1-cm MLC leaves (Fig. 7) and the 0.5-cm MLC leaves (Fig. 8).

Table 1 shows that the dose to the rectal wall at the 50% volume point on the DVHs is reduced in the plans with fully optimized collimator parameters for all patients. The most commonly used collimator setup procedure (non-optimized situation) provided the

Table 1. Comparison of dose to rectal wall at 50% volume point of DVH

Patient	Dose to 50% Volume of Rectal Wall (Gy) No Optimization	Dose to 50% Volume of Rectal Wall (Gy) Full Optimization	Change in Dose to 50% Volume of Rectal Wall
A	47.7	44.0	8% less dose with optimization
B	43.4	42.0	3.3% less dose with optimization
C	46.5	44.8	3.8% less dose with optimization

Plans done with 1-cm MLC leaves.

Table 2. Comparison of volume of rectal wall receiving more than 60 Gy

Patient	Volume Receiving 60 Gy (cm ³) No Optimization	Volume Receiving 60 Gy (cm ³) Full Optimization	Change in Volume of Rectal Wall Receiving 60 Gy
A	4.2	4.4	4.7% reduction in rectal wall irradiated to > 60 Gy with optimization
B	6.4	6.6	3.0% reduction in rectal wall irradiated to > 60 Gy with optimization
C	3.1	3.4	9.6% reduction in rectal wall irradiated to > 60 Gy with optimization

Plans done with 1-cm MLC leaves.

worst result in all cases analyzed. Similarly, Table 2 shows that for the fully optimized scenario there is a reduction in the volume of rectal wall receiving doses greater than 60 Gy. This is most noticeable in patient C. As stated in these previously cited studies, these reductions in rectal dose would be predicted to lead to a decrease in the probability of both long- and short-term rectal complications.

DISCUSSION

This study reveals that collimator optimization strategies such as utilizing either collimator angle optimization, primary collimator position optimization, or optimization of both of these parameters simultaneously resulted in a reduction of rectal wall volume dose over the non-optimized technique. The non-optimized technique is currently the most common technique employed in radiotherapy departments, although the fully optimized situation demonstrated the best results in its ability to reduce the rectal wall dose. The implementation of any one of these optimized techniques does not require the addition of any hardware or software to most linear accelerators or treatment planning systems. These are simple techniques that utilize currently available technology and are therefore techniques that can easily be implemented in any radiotherapy department. The application of these techniques need not be limited to IMRT plans, but can be applied to 3D planning, and should result in similar reductions of dose to the rectum or any other structure of interest.

CONCLUSIONS

This study has shown that through the optimization of collimator angle and primary collimator positions, in conjunction with IMRT planning for prostate cancer, it is possible to reduce the dose delivered to the volume of the rectal wall. Optimization of the collimator angle allows improvement of the conformality of the MLC leaves to the rectal volumes, therefore providing increased shielding to this normal structure. Optimizing the primary collimators so that they do not extend beyond the maximum extent of the MLC opening ensures that transmission through

leaves to the patient is kept to a minimum. This MLC transmission reduction is especially important in IMRT planning, where commonly, an increased number of monitor units is delivered daily and therefore an increased dose is delivered to the patient through interleaf and intraleaf leakage.

The application of collimator and jaw optimization is effective in reducing dose to the rectal wall volume and could be equally applied to other radiosensitive critical structures near target volumes in various anatomic sites.

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