

Clinical Study

Decreasing the Dose to the Rectal Wall by Using a Rectal Retractor during Radiotherapy of Prostate Cancer: A Comparative Treatment Planning Study

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Aim. The aim of the study was to examine the dosimetric effect of rectal retraction, using a rectal retractor, by performing a comparative treatment planning study. **Material and Methods.** Treatment plans using volumetric arc therapy (VMAT) were produced for ten patients both with and without rectal retraction. A hypofractionation scheme of 42.7 Gy in seven fractions was used. The dose to the rectal wall was evaluated for both methods (with and without retraction) using four dose-volume criteria: $V_{40.1\text{ Gy}}$, $V_{38.3\text{ Gy}}$, $V_{36.5\text{ Gy}}$, and $V_{32.6\text{ Gy}}$. **Results.** The retraction of the rectal wall increased the distance between the rectal wall and the prostate. The rectal wall volume was reduced to zero for all dose-volume values except for $V_{32.6\text{ Gy}}$, which was 0.2 cm^3 in average when the rectal retractor was used. **Conclusion.** There was a significant decrease of $V_{40.1\text{ Gy}}$, $V_{38.3\text{ Gy}}$, $V_{36.5\text{ Gy}}$, and $V_{32.6\text{ Gy}}$ when the rectal retractor was used without compromising the dose coverage of planning target volume (PTV).

1. Introduction

The uncertainties in positioning together with movements of the prostate due to varying filling of the rectum and the bladder [1] imply the use of a margin from the clinical target volume (CTV) to the planning target volume (PTV) [2]. Rectal irradiation side effects are due to the large PTV margin and the proximity of the prostate and the rectal wall [3], which often leads to a compromise between target dose coverage and sparing of the rectal wall. Image guided radiotherapy (IGRT) with fiducials in the prostate used for daily verification prior to each treatment reduces the CTV to PTV margin, which decreases the dose to the rectal wall [4]. External beam radiotherapy (EBRT) of prostate cancer can be delivered with three-dimensional conformal radiotherapy (3D-CRT) or intensity modulated radiotherapy (IMRT) [4–7]. IMRT is delivered either with a number of static beams or

as volumetric modulated arc therapy (VMAT). Also, proton beam therapy is used either as boost in combination with EBRT using photons or as the only treatment method [8–10].

Various techniques to decrease the rectal dose have been introduced, such as spacer gels and endorectal balloons [11–15]. The spacer gel is injected between the prostate gland and the anterior rectal wall, which increases the distance in between, resulting in significantly decreased dose to the rectal wall [11–13]. The endorectal balloon is placed in the rectum and inflated with air to expand the rectum [13, 14]. The anterior rectal wall moves toward the prostate and displaces it frontally, while the posterior wall remains in its position resulting in an increased distance between the prostate and the posterior wall [14]. Since the rectal balloon reduces variations in rectum filling and immobilises the prostate, the PTV margin can be reduced, which results in a lower dose to the posterior rectal wall [11–13].

A method introducing a rectal retractor which increases the distance between the prostate and the rectal wall during proton boost treatment has been described [16]. The rectal volume receiving more than 70 Gy ($V_{70\text{Gy}}$), in equivalent dose in 2 Gy fractions (EQD2), was reduced by 77% when the rectal retractor was used compared to treatment without the retractor. Between 2001 and 2008, 147 patients were treated with this method resulting in decreased mean dose to the rectum and notably low rate of rectal toxicity [9].

According to a number of studies the α/β value for prostate cancer is low, approximately 1.5–3 Gy [17–21]. The surrounding organs at risk (rectum and bladder, OAR) have estimated α/β ratio between 3 and 6 Gy [22, 23]. Due to the lower α/β ratio for the prostate, hypofractionation is assumed to be beneficial in radiotherapy of prostate cancer [17, 20, 22, 23].

The aim of the present study was to investigate if a rectal retractor used during EBRT with photons could decrease the dose to the rectal wall. Treatment plans were produced both with and without the rectal retractor with a prescribed dose of 42.7 Gy in 7 fractions [24] using VMAT. The rectal wall volumes receiving more than 70, 65, 60, and 50 Gy ($V_{70\text{Gy}}$, $V_{65\text{Gy}}$, $V_{60\text{Gy}}$, and $V_{50\text{Gy}}$) were investigated, as proposed by the QUANTEC study [25]. According to the LQ-model [26–29] using $\alpha/\beta = 3\text{Gy}$, the corresponding criteria for the fractionation scheme in this study were $V_{40.1\text{Gy}}$, $V_{38.3\text{Gy}}$, $V_{36.5\text{Gy}}$, and $V_{32.6\text{Gy}}$.

2. Material and Methods

2.1. Patients. Ten patients (age 59–80, mean 73 years) with biopsy proven, localised adenocarcinoma of the prostate; nine high risk patients (T2-T3, Gleason ≥ 8 , PSA ≥ 20); and one intermediate risk patient (T2b and T2c, 6 < Gleason < 8, 10 < PSA < 20) were included in the study.

2.2. Patient Immobilisation and Positioning. For treatment planning purposes, all patients underwent two CT scans using a Brilliance CT Big Bore (Philips, Netherlands) with 3 mm slice thickness: first one with standard immobilisation without the rectal retractor, directly followed by one where the retractor was used. The cylindrical shaped retractor was made in water-equivalent plastic, with a diameter of 20 mm and 110 mm length. Laxative was prescribed prior to the CT imaging, and gas was removed by suctioning when the retractor was in place. The rectal retractor was fixed onto a base plate where also leg supports were mounted. The retractor was inserted into the rectum and used to retract the rectum in the dorsal direction (Figure 1). The retraction was limited by the discomfort of the patient.

2.3. Target Volumes and Organs at Risk. The prostate gland was contoured and defined as the CTV, and magnetic resonance imaging (MRI) was used together with CT as support for the target delineation. A CTV to PTV margin of 6 mm was used in all directions, except in dorsal direction (next to the anterior rectal wall) where it was 3 mm both with and without the retractor. The same CTV to PTV margin was

used for comparative purposes. Depending on the treatment technique, a clinical adequate margin would be between 5 and 10 mm in all directions. The rectal wall and the bladder were outlined as OAR. The rectal wall was defined as the volume between the outer contour of the rectum and the inner limit of the mucosa, with a length of 2 cm above and below the PTV in the longitudinal direction.

2.4. Treatment Planning and Evaluation Criteria. For treatment planning, Oncentra 4.0 (Elekta, Sweden) was used. VMAT treatment plans using one full arc (182–178 degrees) were produced both with and without the rectal retractor. The prescribed dose was 42.7 Gy in 7 fractions [24] corresponding to 78.0 Gy in EQD2, calculated with the LQ-model and $\alpha/\beta = 3\text{Gy}$ [27, 28, 30].

The evaluation criteria, presented in Table 1, were selected according to the QUANTEC study [25]. Due to different PTV margins and the possibility to retract the rectal wall, the criteria were lower in this study than those used in the QUANTEC study.

2.5. Statistics. Statistical analysis was performed using R version 2.15.2. The paired *t*-test was used when there was evidence for normal distribution, using Shapiro-Wilk test. Sign test was used if there was no normal distribution.

3. Results

The criterion for PTV dose coverage was fulfilled for all treatment plans, where the average dose to 98% of the PTV was 41.8 Gy (ranging from 41.6 Gy to 42.4 Gy) with retractor and 41.6 Gy (40.9–42.1 Gy) without the retractor.

There was a significant decrease of the rectal wall volume when using the rectal retractor as shown in Table 2. The *P* values were calculated with the sign test.

The DVHs of the rectal wall with and without retractor for one representative patient are presented in Figure 2.

The shortest distance between the CTV and the rectal wall (outer contour) was measured in the CT-studies for all patients both with and without retractor. The average distance increased significantly when the rectal retractor was used, 4 mm (2–6 mm) with and 1 mm (0–5 mm) without retractor ($P = 0.00004$ using *t*-test).

All treatment plans reached the dose-volume constraint ($V_{36\text{Gy}} < 50\%$) for the bladder volume. The DVHs for the bladder were very similar when comparing results with and without retractor for each patient indicating that the rectal retractor did not influence the dose distribution in the bladder. A DVH of the bladder for one representative patient is presented in Figure 3.

When the rectal retractor was used, the volume of the rectal wall ($P < 0.05$ using *t*-test) and the bladder ($P < 0.05$ using sign test) was significantly increased (see also Figure 2). No significant volume changes for the prostate ($P = 0.91$ using *t*-test) could be detected; see Table 3.

TABLE 1: Evaluation criteria used for the optimisation, selected from QUANTEC [25]. Due to different PTV margins and the possibility to retract the rectal wall, the limits were lower in this study.

Priority	Structure	Present study criteria	QUANTEC criteria
1	PTV	$D_{98\%} \geq 95\%$	
2	Rectal wall	$V_{40.1\text{Gy}} \leq 0\text{ cm}^3$	$V_{70\text{Gy}} < 8\text{ cm}^3^*$
2	Rectal wall	$V_{38.3\text{Gy}} \leq 1\text{ cm}^3$	$V_{65\text{Gy}} < 10\text{ cm}^3^*$
2	Rectal wall	$V_{36.5\text{Gy}} \leq 1\text{ cm}^3$	$V_{60\text{Gy}} < 14\text{ cm}^3^*$
2	Rectal wall	$V_{32.6\text{Gy}} \leq 1\text{ cm}^3$	$V_{50\text{Gy}} < 20\text{ cm}^3^*$
3	Bladder	$V_{32.6\text{Gy}} \leq 50\%$	

*The volumes are expressed in relative volume in QUANTEC. It is translated to absolute dose for a rectal wall volume of 40 cm³.

TABLE 2: $V_{40.1\text{Gy}}$, $V_{38.3\text{Gy}}$, $V_{36.5\text{Gy}}$, and $V_{32.6\text{Gy}}$ of the rectal wall with and without the rectal retractor. The range is given within brackets.

	$V_{40.1\text{Gy}}$ (cm ³)	$V_{38.3\text{Gy}}$ (cm ³)	$V_{36.5\text{Gy}}$ (cm ³)	$V_{32.6\text{Gy}}$ (cm ³)
With retractor	0.0 (0.0-0.0)	0.0 (0.0-0.1)	0.0 (0.0-0.2)	0.2 (0.0-0.8)
Without retractor	0.5 (0.0-2.0)	0.8 (0.0-3.1)	1.3 (0.1-4.0)	2.5 (0.2-6.8)
Significance	$P = 0.004$	$P = 0.020$	$P = 0.001$	$P = 0.001$

TABLE 3: The average volume of the prostate (CTV), rectal wall, and the bladder with and without the rectal retractor (range).

	With retractor (cm ³)	Without retractor (cm ³)	Volume difference (cm ³)
Prostate	45 (24-67)	45 (28-81)	0
Rectal wall	46 (37-58)	35 (25-57)	11 (+31%)
Bladder	156 (60-371)	144 (47-353)	12 (+8%)

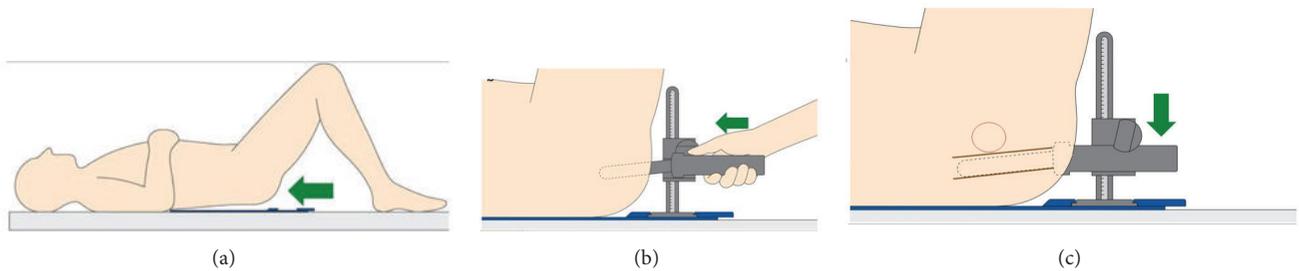


FIGURE 1: An illustration describing how the rectal retractor is placed in the rectum and retracted towards the treatment table.

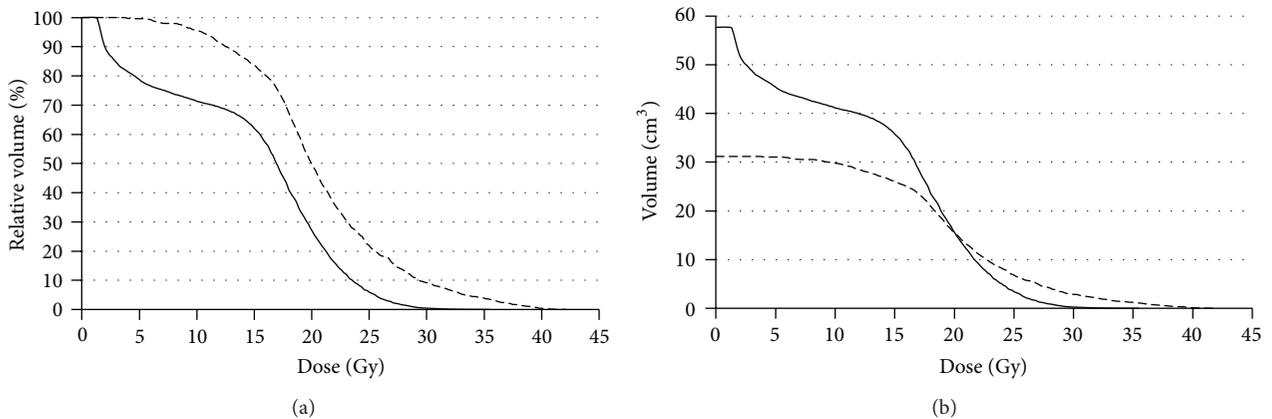


FIGURE 2: DVH of the rectal wall for one representative patient, where the solid line is with retractor and the dashed line is without the retractor. In the left DVH, the rectal volume is presented as relative volume (%) and in the right DVH the volume is presented as absolute volume. Note that the volume is larger with retractor compared to without.

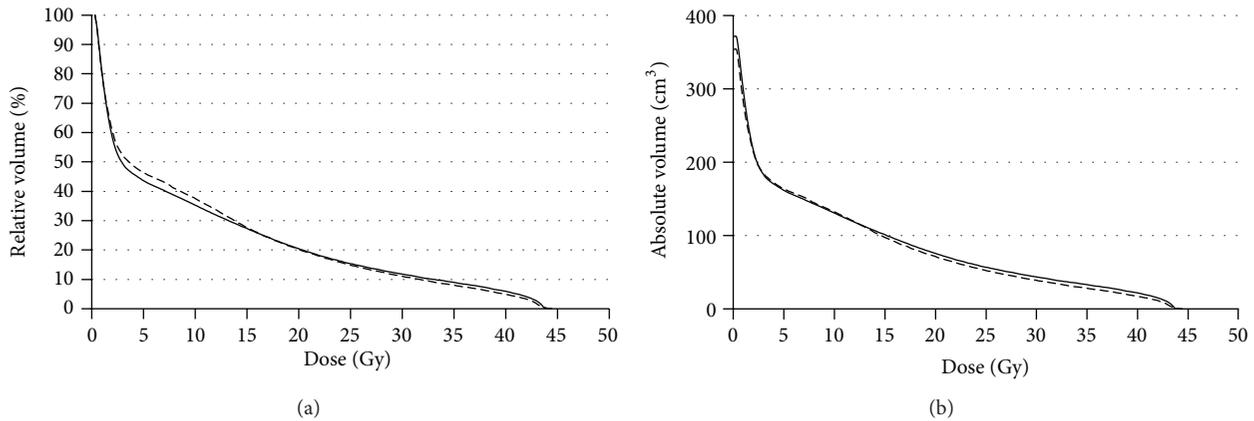


FIGURE 3: DVH of the bladder for one representative patient, where the solid line is with retractor and the dashed line is without the retractor. In the left DVH, the bladder volume is presented as relative volume (%) and in the right DVH the bladder volume is presented as absolute volume. Note that the rectal retractor does not influence the dose to the bladder volume.

4. Discussion

In this study, the rectal wall sparing effect of a rectal retractor was investigated. The same delineation and treatment technique was used for treatment planning both with and without the rectal retractor. The dose-volume criteria $V_{40.1 \text{ Gy}}$, $V_{38.3 \text{ Gy}}$, $V_{36.5 \text{ Gy}}$, and $V_{32.6 \text{ Gy}}$ were investigated for the rectal wall volume. When the rectal retractor was used, there was a significant decrease in irradiated rectal wall volume compared to treatment without the retractor; see Figure 4.

The movements of the prostate due to varying filling of the rectum and the bladder imply a large CTV to PTV margin to ensure that the prostate receives the prescribed dose [1, 3]. Daily IGRT in combination with fiducials in the prostate gland for daily verification of the prostate and correction of the patient positioning prior to each treatment is an important method to reduce PTV margins [3]. The intrafractional reproducibility of the rectal wall position is increased when the retractor is used, and it prevents variation of filling [16]. Due to decreased rectal motion, the prostate gland was immobilised allowing for a safe reduction of the PTV margin [14]. This has not been done in this study, where the same PTV margins were used for delineation both with and without retractor. In spite of that, there was a significant decrease in dose to the rectal wall with the retractor. The values for $V_{40.1 \text{ Gy}}$, $V_{38.3 \text{ Gy}}$, $V_{36.5 \text{ Gy}}$, and $V_{32.6 \text{ Gy}}$ are 2–4 times larger without retraction if the PTV margin is increased from 3 mm to 7 mm in the dorsal direction (data not presented). Therefore, the rectal wall sparing effect of the retractor is assumed to be even larger if clinically adequate margins were used without retraction.

The rectal retractor mechanically pushes the posterior rectal wall into the dorsal direction. The rectal wall will then be both stretched and retracted. The delineated posterior part of the rectal wall gets thinner and the delineated anterior part gets more stretched out, which increases the rectal wall volume in the low dose region, as shown schematically in Figure 5. The increased distance between the rectal wall and the CTV (prostate) lowers the dose in the rectal wall. The thickening of the rectal wall and the increased distance

between the rectal wall and the CTV lead to an even larger difference in distance from the inner mucosa to the CTV. Although the rectal wall volume increases when using the retractor, the net effect is a significant decrease in volumes receiving high dose levels.

There are other methods to immobilise and displace the rectal wall. There are different gels that are injected between the prostate and the anterior rectal wall [12, 13, 31], which increases the distance in between, resulting in significantly decreased rectal wall dose. The rectal balloon is another method where an uninflated balloon is placed in the rectum and inflated with air to expand the rectum. The anterior rectal wall moves toward the prostate and displaces it frontally, and the posterior wall remains in its position resulting in an increased distance between the prostate and the posterior wall [14]. Since the rectal balloon reduces variations in rectum filling and immobilises the prostate, PTV margin can be reduced, which results in a lower dose to the rectal wall [14, 15, 32].

There may be a risk of mechanically induced rectal complications if the rectal retractor would be used for a large number of fractions. Several hundred patients have been given proton [9] and photon boost therapy with four fractions and a few patients with seven fractions using the rectal retractor without complications. The patients have been followed up carefully regarding acute and late effects of radiotherapy. During ten years of proton boost therapy with the rectal retractor, there have been no late effects due to the retractor. The risk of complications is therefore assumed to be negligible if the retractor is used a limited number of times as with hypofractionated treatment. Fortunately, prostate cancer patients are eligible for hypofractionated treatment due to the low α/β ratio (1.5–3 Gy) [17–21] compared to the surrounding healthy tissue (3–6 Gy) [22, 23]. The hypofractionation scheme used in the present study, 42.7 Gy in 7 fractions [24], shortens the total treatment time from eight weeks with conventional treatment (2 Gy per fraction for 39 fractions) to less than three weeks. Thereby it is possible to use the rectal retractor for all fractions. The hypofractionated approach is not considered as standard treatment. However,

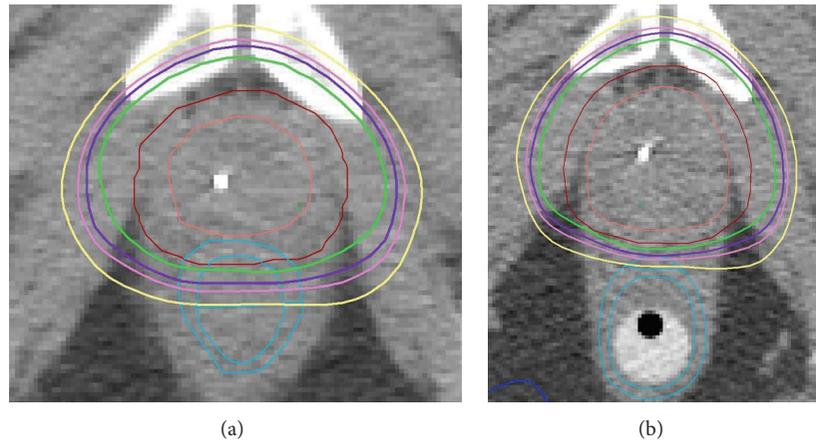


FIGURE 4: Axial CT slices for one representative patient. The left image shows the dose distribution without the rectal retractor and the right image with the retractor. The CTV is the red structure, the PTV is the light blue, and the rectal wall structure is in cyan. The isodose lines correspond to 40.6 Gy (green), 38.3 Gy (purple), 36.5 Gy (pink), and 36.5 Gy (yellow).

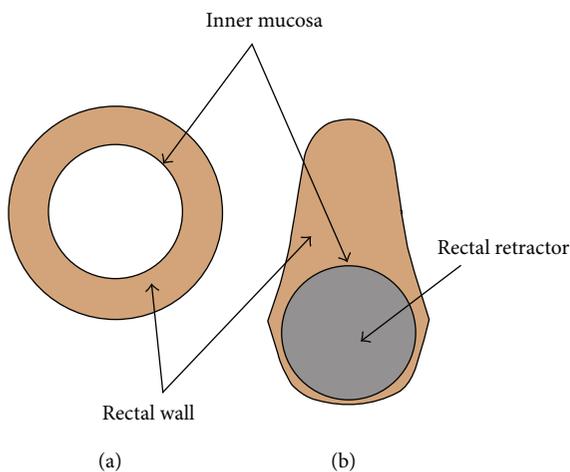


FIGURE 5: A schematic illustration of the impact of the rectal retractor on the rectal wall in the ideal case, where the situation is shown without the retractor (a) and with the retractor (b). The brown area indicates the rectal wall and the grey circle represents the rectal retractor.

the Swedish hypofractionation study [24] has been ongoing for several years and will include 1000 patients. There have been interim analyses at several times during the study with good enough results to continue the study. The positioning becomes more critical with hypofractionated treatment since every fraction represents a large part of the total treatment. The rectal retractor fixates the rectal wall and prevents gases and filling to pass through during treatment, which reduces the movements of the prostate [14]. The reduced intrafraction motion decreases the uncertainty of the location of the prostate over time and the hypofractionated treatment will be safer.

There is a close relationship between chronic rectal toxicity and rectal wall volume after irradiation to doses over 50 Gy [23, 26, 29]. Dose-volume value $V_{70\text{Gy}}$ between 5 and 15 cm³ is associated with a 13% risk of grade 2 or higher

chronic rectal complications and $V_{70\text{Gy}}$ between 0 and 5 cm³ with an 8% risk [29]. With the rectal retractor, $V_{40.1\text{Gy}}$ is 0.0 cm³ (0.0–0.0 cm³), which indicates no risk of grade 2 or higher chronic rectal complications. Since the corresponding $V_{32.6\text{Gy}}$ -value is 0.2 cm³ (0.0–0.8 cm³), the risk of chronic rectal toxicity should be very low.

5. Conclusions

The rectal wall sparing effect by using a rectal retractor was investigated in a comparative treatment planning study. The same target delineation and treatment technique was used for treatment planning both with and without the rectal retractor. The irradiated rectal wall volumes $V_{40.1\text{Gy}}$, $V_{38.3\text{Gy}}$, $V_{36.5\text{Gy}}$, and $V_{32.6\text{Gy}}$ were used to investigate the impact of the rectal retractor. There was a significant decrease of $V_{40.1\text{Gy}}$, $V_{38.3\text{Gy}}$, $V_{36.5\text{Gy}}$, and $V_{32.6\text{Gy}}$ when the rectal retractor was used without compromising the dose coverage of PTV.

Conflict of Interests

The authors have no conflict of interests to report. The authors alone are responsible for the content and writing of the paper.

Authors' Contribution

Kristina Nilsson, Andreas K. Johansson, Gunilla Ljung, and Ulf Isacson have contributed equally to this study.

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