Stepping source prostate brachytherapy: From target definition to dose delivery
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Chapter 3
Deviations from the planned dose during 48 hours of stepping source prostate brachytherapy caused by anatomical variations

Anna M. Dinkla, Bradley R. Pieters, Kees Koedooder, Philip Meijnen, Niek van Wieringen, Rob van der Laarse, Johan N. van der Grient, Coen R.N. Rasch and Arjan Bel

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3.1 Abstract

Background: To determine the uncertainties in planned dose associated with catheter and organ movement during 48 hours of stepping source prostate brachytherapy.

Methods: Pulsed-dose rate (PDR) prostate brachytherapy as a boost is given in 24 pulses every 2 hours, making the total treatment last 48 hours. The entire treatment is based on one plan, created on the planning CT (CT1). Two follow-up CTs (CT2 and CT3) were acquired; halfway through the treatment and at the end of treatment. On these repeat scans the catheters were reconstructed and PTV and OARs were delineated. The original treatment plan was calculated on the repeat CTs. Target coverage $V_{100\%}$, $D_{90\%}$ dose to 2 cm$^3$ (D2cm$^3$) of the rectum and bladder and dose to 0.1 cm$^3$ of the urethra were recorded from the recalculated DVHs.

Results: On the two repeat CTs the $V_{100\%}$ decreased -1.5% and -2.3% as compared to the planning CT. For the rectum D2cm$^3$, the average increase was 14.8% (CT1–CT2) and 17.3% (CT1–CT3). Increase in bladder D2cm$^3$ was on average 23.1% (CT1–CT2) and 24.8% (CT1–CT3). For the urethra D0.1cm$^3$ an average decrease of -2% (CT1–CT2) and -3.2% (CT2–CT3) was observed.

Conclusions: Changes in target coverage during treatment were small and considered clinically irrelevant. However, an overall increase in dose to the OARs was found as compared to the planned dose, which should be taken into account during treatment planning.

Keywords: Prostate cancer, Brachytherapy, Pulsed-dose rate, High-dose rate, Uncertainties, Dose variation
3.2 Background

For intermediate- to high-risk prostate cancer, external beam radiotherapy (EBRT) with a boost to the prostate is a commonly used treatment allowing a higher dose to the prostate while sparing the organs at risk (OARs) as much as possible [1]. This boost can be delivered with brachytherapy, which is a local treatment characterised by its steep dose gradient. Brachytherapy dose distributions generally display large heterogeneity, making them very sensitive to a change in the source locations. Therefore, the validity of the planned dose throughout the treatment depends on both stable catheters and anatomy. Deviations from the planned dose cause a risk of underexposure of the target and overexposure of the OARs.

At our institute, the boost is delivered using pulsed-dose rate (PDR) brachytherapy, applying 24 low-dose pulses during 48 hours. This treatment type results in good clinical outcome [2-4] and can be used as an alternative to a high-dose rate (HDR) treatment due to comparable biological effectiveness [5].

Both gastrointestinal and gastrourinary toxicities are known to be associated with dose [6,7]. Dose is represented by dose–volume histogram (DVH) parameters, which are extracted from the treatment plan. The treatment is based on initial imaging, such as a planning CT, representing the situation a few hours after implantation. However, during treatment, geometric changes will occur. Rectum and bladder filling influence their shape, volume and position with respect to the prostate [8,9]. Changes in patient positioning can also cause deviations between the planned dose and the actual dose delivered [10].

Prostate volume is influenced by oedema caused by catheter insertion injury and bleeding. For permanent seed implants, the main increase in prostate volume (10–30%) occurs during the first 24 hours after implantation, and resolves in the next weeks [11,12]. Prostate oedema can influence $V_{100\%}$ and dose to the prostate ($D_{90}$), which are shown to correlate with local control [13]. Additionally, for temporary implants, displacement of the catheters can affect target coverage, especially at the basal side of the prostate, ranging from minor coverage loss [14] to more severe loss (13–20%) [15-17]. With self-anchoring catheters displacement is minimal [18].

In brachytherapy, the PTV is in general identical to the CTV since the implant moves with the target volume [19]. However, within the brachytherapy community, interest has grown in the use of margins to compensate for uncertainties in target coverage. But since applying a planning margin to the CTV without modifying catheter locations may result in higher doses within the target volume [20], the solution would be to extend the implanted volume. This study addresses this question of whether or not to use margins. Our results hold for a PDR brachytherapy treatment using self-anchoring needles, but in
general can also be applied for HDR when multiple fractions are given with one implant, which is often the case [21].

The aim is to quantify the dosimetric effect of geometrical changes during 48 hours of stepping source prostate brachytherapy, by evaluating dose delivery on repeat CT scans.

### 3.3 Methods

**External beam radiation therapy**

Data were used from 31 patients, treated between May 2003 and March 2005 with conformal EBRT, followed by a PDR boost. These patients were treated according to a study protocol investigating displacement of anchoring catheters. The Medical Ethics Committee approved this study and written informed consent was obtained from all patients. The CTV for EBRT consisted of the lower pelvic lymph nodes, the prostate and base of the seminal vesicles. A dose of $23 \times 2\,\text{Gy}$ to at least 95% of the PTV was given using a conformal box technique.

**PDR brachytherapy**

Catheter implantation was performed one week after the end of EBRT according to a preplan. This procedure is described in detail elsewhere [18]. During implantation a transurethral balloon-catheter was introduced into the bladder. Also, three fiducial markers were placed in the prostate, two at the base and one at the apex, to help with the recognition of these structures on the CT-scans. Positioning of the markers was done under ultrasound guidance.

After implantation a planning CT (CT1) was made with 2 mm slice thickness, on which the prostate and OARs were delineated. The PTV was defined as the prostate without margin. After delineation, dwell-times were optimised using manual graphical optimisation to cover at least 95% of the PTV with the prescribed dose (PD). The treatment plan was created in PLATO BPS v14 (Nucletron, Veenendaal, The Netherlands).

When we started the procedure in 2003 the total dose delivered by PDR was 24.96 Gy given in 1.04 Gy pulses, given every 2.2 hours. When the technique was proven feasible [2] it was decided to escalate the dose to 1.2 Gy per fraction with a period time of 2 hours, making the total treatment approximately 48 hours. For this study, the prescription dose of all treatment plans was changed to 1.2 Gy/pulse, in order to investigate whether the changes in dose during treatment affect the dose according to our current planning constraints.

Planning constraints for $2\,\text{cm}^3$ of the rectum were $\text{Re-D2cm}^3 < 80\%$ of PD (96 cGy/pulse) and for $2\,\text{cm}^3$ of the bladder $\text{Bl-D2cm}^3 < 120\%$ of PD (144 cGy/pulse). These constraints
Deviations from the planned dose

are based on maximum tolerance doses to the highest exposed $D_{2cm^3}$ of the OARs (applying an $\alpha/\beta$-ratio of 3 Gy): 70 Gy EQD$_2$ for the rectum and 90 Gy EQD$_2$ for the bladder. The planning constraint for the urethra was $Ur-D_{0.1cm^3} < 140\%$ of PD (168 cGy/pulse).

Repeat CT-scans
For all 31 patients a planning CT was acquired immediately following implantation (planning CT or CT1). They received a second CT-scan on the day after the implantation (CT2) and 25 patients received a third scan on the second day (after approximately 48 hours), right before the end of treatment (CT3).

All follow-up CT-scans were loaded in our treatment planning system (Oncentra Brachy, Nuclertron, Veenendaal, The Netherlands), that had replaced PLATO BPS v14. One physician (P.M.) delineated the prostate and OARs, supported by the delineation of the planning CT and the fiducial markers. A second observer (B.P.) reviewed the contours. Disagreements in contouring were discussed and adapted on the basis of consensus. The catheters were again reconstructed on all repeat CTs after which the original treatment plan was recalculated on these datasets by transferring the loading pattern (active dwell positions and their weights). DVH parameters of the newly delineated organs on the repeat CTs were compared with the originally planned parameters on CT1.

PTV and dose coverage
We have previously reported minimal displacement using our self-anchoring catheters [18]. However, in that earlier study we had not reconstructed the catheters on the repeat CTs, neither did we take shape variation of PTV and OARs into account by again delineating the structures on the repeat CTs. DVH parameters were recorded from the two repeat CTs to determine the deviations from the planned dose: target volume, target $V_{100\%}$ and minimal dose to 90% of the prostate volume $D_{90}$.

OAR dose and rectum position
On all scans the distance between rectum and prostate was measured. Since the minimum distance was often zero, this measure was not a good representation of the prostate-rectum distance. We divided the prostate in three sections in the longitudinal direction: apex, base and mid-plane section. For each section the minimum and maximum distance between the surfaces of the prostate and the rectum was measured (midway between the left and the right of the prostate surface). Final prostate-rectum distance was represented by the average of these six measures.

To quantify the variation during treatment, bladder and rectum $D_{2cm^3}$ (Bl-$D_{2cm^3}$ and Re-$D_{2cm^3}$) were recorded, as well as the Re-$V_{80\%}$ (rectal volume receiving $\geq 80\%$ of the PD). For the urethra, dose to 0.1 cm$^3$ ($Ur-D_{0.1cm^3}$) was analysed.
Statistics
The DVH parameters acquired from the repeat CTs were compared to those from the treatment plan using Student’s t-test. Because of the non-normality of these parameters, $V_{100\%}$ and PTV were tested with a Wilcoxon signed-rank test. All tests were two-sided and a p-value < 0.05 was considered statistically significant. To test if rectum dose correlated to rectal volume and prostate-rectum distance, Pearson’s correlation test was performed. Statistical analysis was performed with the Statistical Package for the Social Sciences (IBM SPSS Statistics 19, Chicago, IL, USA).

3.4 Results

PTV and dose coverage
Variation in volume of the PTV was small (Table 1), with a maximum volume change of -14% PTV for both CT2 and CT3. Dose coverage ($V_{100\%}$ and $D_{90}$) as a function of scan number is shown in Figure 1 (a and b). $V_{100\%}$ changed during treatment, although mean difference was only -2.3% for CT1–CT3 with a largest decrease in $V_{100\%}$ of -10%. Despite the small decrease, the planning constraint $V_{100\%} > 95\%$ was not achieved for 65% (20/31) of the patients on CT2 and for 72% (18/25) on CT3 (Figure 1a). $D_{90}$ showed largest variation with respect to the original plan. However, $D_{90}$ remained higher than the prescribed dose for most patients; for 94% of the patients on CT1, for 90% on CT2 and for 88% on CT3 (Figure 1b).

OAR dose and rectum position
Rectal dose increased during treatment. Mean Re-$V_{80\%}$ was 0.27 cm$^3$ (range: 0–1.06 cm$^3$) during planning, but increased to 1.14 cm$^3$ (range: 0–7.4 cm$^3$) and 1.34 cm$^3$ (range: 0–5.23 cm$^3$) for CT2 and CT3, respectively. The average prostate-rectum distance measured on the CT1 for all patients was 7.1 mm and had decreased 1.2 mm after 24 hours, as measured on CT2 (Table 2). After 48 hours, the distance was smallest (5.3 mm). The difference between CT1–CT2 was statistically significant ($p = 0.027$), but the decrease between CT2–CT3 was not ($p = 0.12$).

Re-$D_{2cm^3}$ generally increased during treatment (Figure 1c). On CT1, Re-$D_{2cm^3}$ never exceeded the tolerance dose. On CT2 the dose was above the tolerance dose in 7 of 31 patients (23%). One patient out of these seven did not receive a third CT, but for five of the remaining six the dose exceeded the tolerance dose at CT3. Mean increase was 13.3% between CT1 and CT2 and 17.3% between CT1 and CT3 (Table 3). The increase in Re-$D_{2cm^3}$ on CT2 as compared to the planning CT was statistically significant ($p = 0.001$), but the difference between CT2 and CT3 was not ($p = 0.42$).
Table 1. Differences in DVH parameters of the target. All changes are expressed as relative values (%) as compared to the planned value (CT1).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Planned (CT1)</th>
<th>CT2 (%)</th>
<th>CT3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTV Mean</td>
<td>34.2 cm³</td>
<td>0.03</td>
<td>0.18</td>
</tr>
<tr>
<td>PTV Median</td>
<td>32.6 cm³</td>
<td>0.64</td>
<td>0.00</td>
</tr>
<tr>
<td>PTV SD</td>
<td>8.8 cm³</td>
<td>3.90</td>
<td>4.36</td>
</tr>
<tr>
<td>V₁₀₀% Mean</td>
<td>95.7%</td>
<td>-1.52</td>
<td>-2.32</td>
</tr>
<tr>
<td>V₁₀₀% Median</td>
<td>95.9%</td>
<td>-1.44</td>
<td>-2.84</td>
</tr>
<tr>
<td>V₁₀₀% SD</td>
<td>3.1%</td>
<td>-2.96</td>
<td>3.53</td>
</tr>
<tr>
<td>D₉₀ Mean</td>
<td>132.1 cGy</td>
<td>-3.23</td>
<td>-4.17</td>
</tr>
<tr>
<td>D₉₀ Median</td>
<td>132.4 cGy</td>
<td>-3.88</td>
<td>-5.65</td>
</tr>
<tr>
<td>D₉₀ SD</td>
<td>7.0 cGy</td>
<td>4.71</td>
<td>5.34</td>
</tr>
</tbody>
</table>

Parameters in bold are statistically significantly different from CT1.

Figure 1: Box plots showing (a) target coverage V₁₀₀% variation during treatment, (b) target dose (D₉₀), (c) rectum dose (Re-D2cm³) and (d) bladder dose (Bl-D2cm³). The dashed lines represent the planning objectives and the dots represent the observations of the individual patients (jittered for visualisation).
Table 2. Prostate-rectum distances measured in three sections of the prostate (apex, midplane and base).

<table>
<thead>
<tr>
<th></th>
<th>Apex</th>
<th></th>
<th>Midplane</th>
<th></th>
<th>Base</th>
<th></th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td></td>
</tr>
<tr>
<td><strong>CT1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>4.1</td>
<td>10.1</td>
<td>3.2</td>
<td>7.1</td>
<td>5.8</td>
<td>11.9</td>
<td>7.1</td>
</tr>
<tr>
<td>Median (mm)</td>
<td>4.0</td>
<td>10.0</td>
<td>3.0</td>
<td>6.0</td>
<td>4.0</td>
<td>10.0</td>
<td>6.8</td>
</tr>
<tr>
<td>SD (mm)</td>
<td>1.8</td>
<td>3.4</td>
<td>1.4</td>
<td>3.9</td>
<td>4.5</td>
<td>6.9</td>
<td>2.7</td>
</tr>
<tr>
<td><strong>CT2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>3.8</td>
<td>8.4</td>
<td>2.5</td>
<td>6.0</td>
<td>4.6</td>
<td>10.0</td>
<td>5.9 1</td>
</tr>
<tr>
<td>Median (mm)</td>
<td>4.0</td>
<td>7.0</td>
<td>2.5</td>
<td>6.0</td>
<td>4.0</td>
<td>8.5</td>
<td>5.7</td>
</tr>
<tr>
<td>SD (mm)</td>
<td>2.0</td>
<td>3.3</td>
<td>1.1</td>
<td>2.5</td>
<td>2.9</td>
<td>5.4</td>
<td>2.1</td>
</tr>
<tr>
<td><strong>CT3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (mm)</td>
<td>3.7</td>
<td>9.0</td>
<td>1.9</td>
<td>5.4</td>
<td>3.6</td>
<td>8.2</td>
<td>5.3 2</td>
</tr>
<tr>
<td>Median (mm)</td>
<td>3.0</td>
<td>8.5</td>
<td>2.0</td>
<td>5.0</td>
<td>3.0</td>
<td>8.0</td>
<td>5.4</td>
</tr>
<tr>
<td>SD (mm)</td>
<td>1.8</td>
<td>3.5</td>
<td>0.9</td>
<td>2.0</td>
<td>2.1</td>
<td>3.6</td>
<td>1.6</td>
</tr>
</tbody>
</table>

1 CT1–CT2: p = 0.027.
2 CT2–CT3: p = 0.12.

Table 3. Differences in DVH parameters of the OARs. All changes are expressed as relative values (%) as compared to the planned value (CT1).

<table>
<thead>
<tr>
<th></th>
<th>Planned (cGy/pulse)</th>
<th>CT2 (%)</th>
<th>CT3 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re-D2cm³</td>
<td>Mean</td>
<td>72.70</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>74.0</td>
<td>13.2</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>8.7</td>
<td>19.5</td>
</tr>
<tr>
<td>Bl-D2cm³</td>
<td>Mean</td>
<td>75.70</td>
<td>25.4</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>71.7</td>
<td>24.5</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>13.7</td>
<td>28.1</td>
</tr>
<tr>
<td>Ur-D0.1cm³</td>
<td>Mean</td>
<td>154.7</td>
<td>-2.0</td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>153.1</td>
<td>-3.1</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>9.7</td>
<td>4.2</td>
</tr>
</tbody>
</table>

Parameters in bold are statistically significantly different from CT1.

The increase in Re-D2cm³ correlated with the variation in the average prostate-rectum distance ($R^2 = 0.6$, $p < 0.05$) and with the change in rectal volume ($R^2 = 0.4$, $p < 0.05$).

Bl-D2cm³ was generally higher on the repeat CTs as compared to the planning CT.
Deviations from the planned dose

Measured on CT2 Bl-D2cm³ was never higher than the tolerance dose and on CT3 only in 1 of 25 cases (4%) (Figure 1d). The mean increase was 25.4% for CT1–CT2, and 24.8% for CT1–CT3 (Table 3). These changes were statistically significantly different from CT1 (p < 0.001), but not from each other (CT2–CT3, p = 0.64).

Urethral dose was slightly lower on the repeat CTs as compared to the planning CT. Mean Ur-D0.1cm³ was 154.7 cGy per pulse (128.9% of PD) with a mean decrease of -2.0% measured for CT1–CT2, and -3.2% for CT1–CT3 (Table 3). This led to a decrease in the number of patients for which the dose constraint (Ur-D0.1 <140% of PD) was exceeded; On CT1 this was the case for 5 patients, whereas only for 2 patients the constraint was not met on their repeat CT(s).

3.5 Discussion

This study shows that the decrease in target coverage is small during 48 hours of temporary brachytherapy, provided that catheter displacement is minimal. Thus there is no rationale for applying planning margins to the target volume to compensate for volume changes of the prostate. OAR dose was found to increase during treatment, as compared to planning. Special attention should be given to rectum dose, which showed an increasing trend due to decreasing prostate-rectum distance.

A possible limitation in this study was the use of only three scans per patient to evaluate changes in a time period of 48 hours. With three ‘snapshots’ of the rectum and bladder, which are subject to variation, we acquire a brief indication of what happens during the entire treatment. However, to study changes in prostate volume and catheter locations, these three scans are enough to draw valid conclusions. If oedema is present after implantation, it is observed to resolve slowly with a half-time of at least 4 days [11,12].

The patient cohort used for this study was treated seven to nine years ago. Due to the learning curve associated with the implantation procedure, the number of patients for which target coverage was below the constraint was higher than in current clinical practice. However, since the treatment technique has remained the same, we expect our results to be also valid for patients currently treated.

PTV and dose coverage

The mean variation in $V_{100\%}$ during treatment was only -1.5% and -2.3% between the planning CT and CT2 and CT3, respectively. The displacement of our self-anchoring catheters for this patient cohort has been reported previously; mean absolute displacement was around 1 mm [18]. Compared to other studies that report mean losses in dose coverage of 3.5% after ≥6 hours up to 17% the following day [14-16], our decrease in target coverage was small. It must be noted however, that the planning constraint of $V_{100\%}$ >
95% was not achieved in the majority of the patients. This was caused by the relatively low target coverage during planning of these patients, who were the first to be treated at our department. The value for \( D_{90} \) remained above the prescription dose for most of the patients. Although clinical outcome so far is good [2], longer follow-up is needed to conclude on the impact of coverage loss.

In this study, besides catheter reconstruction, also target delineation was performed on the repeat CTs. Prostate delineation suffers from interobserver variation, which is about 15% for the CT-based prostate [22,23]. The contours of CT2 and CT3 were reviewed by the observer who delineated the planning CTs. In this way, contouring variability was kept at a minimum, to be comparable to intraobserver variation (which is about 5%) [22].

The CT scans had a small slice thickness of 2 mm and contained fiducial markers for added reference. However, detecting prostate boundaries and localisation of the prostatic apex are hampered by lack of contrast on CT; the latter affecting the number of slices incorporated in the PTV. Whether prostate delineation inaccuracy should be accounted for by a margin, remains to be studied.

Prostate volume was expected to increase after implantation due to oedema, as observed in permanent implant prostate brachytherapy [11,12]. For these treatments, implantation and planning is usually based on ensuring sufficient target coverage at the time of maximum oedema. Groups performing high-dose rate brachytherapy that used the post-implant CT scan as a reference did not find a volume increase[24,25]. It is therefore likely that oedema occurs within the first few hours after implantation. Alternatively, the differences in the development of oedema can be explained by the differences in treatment modality. For temporary implant brachytherapy, catheters remain in place during treatment, for permanent implant brachytherapy they are removed after seed implantation. Furthermore, the amount of catheters is usually lower in temporary implants. Of course, the well-known difficulties in detecting the prostate boundaries on CT also hamper the volume evaluation. Kim et al. found larger variations in prostate volume of up to 17% between 2 HDR fractions, but concluded that the dosimetric impact of less than 5% was clinically insignificant [25].

Since the differences in prostate volume and target coverage were small, we did not compare the prostate volumes slice-by-slice. In addition, shape variation would be difficult to distinguish from delineation uncertainty. The deformation is expected to be small, although data on prostate deformation during temporary implant brachytherapy are currently not available.

The small changes in prostate volume and target coverage do not indicate the necessity of an additional prostate margin for our PDR boost treatment. Also an adaptive and/or corrective procedure is not considered necessary with the use of self-anchoring
Deviations from the planned dose

Deviations from the planned dose

In other studies on HDR, a margin is often applied to the prostate contour mainly to cover extracapsular/microscopic extension [14,16,26]. Some also apply a PTV margin to compensate for (caudal) displacement of the catheters [27,28]. For instance, Yoshioka et al. apply a 1 cm PTV margin to the basal edge of the prostate, but did not report the actual catheter displacements [27]. Damore et al., who studied catheter displacements prior to 4 boost HDR fractions also applied a 1 cm craniocaudal margin to the target volume to ensure adequate dose coverage after catheter displacements of 1 cm [28]. Another strategy would be to readjust the catheters, or perform a replanning [14-16,26,28]. For displacements larger than 1 cm, Damore et al. performed and recommend repositioning of the catheters. Kovalchuk et al. performed re-adjustments of the catheters and replanning, hereby ensuring adequate target coverage. Without replanning, the 3.5 mm mean catheter displacements would result in a decrease in V\textsubscript{100\%} (of 97–93%) [14]. Foster et al. found a decrease in V\textsubscript{100\%} of the prostate gland (from 93.8% to 76.2%) due to a mean interfraction displacement of 5.1 mm [15]. Their dosimetry was improved after replanning, which was therefore considered feasible. Simnor et al. measured a 4–5% decrease in target coverage after re-adjustment of the catheters before each fraction [16]. These re-adjustments also reduced the differences in planned versus delivered dose to the OARs. Barkati et al. perform pretreatment fluoroscopic imaging to check catheter displacement [26], but did not report actual displacements. A simulation study showed that displacements of 3 mm or greater have significant impact not only on target coverage, but also on dose to the OARs [29]. The authors therefore advise readjustment of the catheters rather than applying a margin.

OAR dose and rectum position

A general increase in rectum dose over the time of treatment was observed, i.e. 13% and 17% between the planning CT and the two repeat CTs. We detected a clear trend, although the rectum is a dynamic organ and a complete representation of the variation during 48 hours cannot be obtained by using three scans. The measured increase in rectal dose was related to a decrease in distance between rectum and prostate that was observed on the follow-up CTs. Other groups studying changes during HDR brachytherapy reported a comparable increase, although they ascribed this to random variations in rectum shape [15] or to a combination of factors including catheter displacement [14,16]. Rectal dose generally seems to increase with caudally displaced catheters, making the solution to add a margin to the prostate to compensate for this not optimal [29].

We did observe a higher incidence of gas pockets inside the rectum on the follow-up CTs, which could partly explain the increase in rectal volume and the decrease in prostate-rectum distance in our data. In some patients we observed disappearance of gas pockets, but a relation between the disappearance of gas pockets and decrease in rectal dose could not be established. This could be explained by the fact that in these cases the
planned dose was already tightly optimised around the rectum.

The decrease in distance could be compensated for by applying a small margin to the rectum. After the first 24 hours, the rectum was on average 1 mm closer to the prostate, which could be sufficient to use as margin. An alternative strategy would be to apply a worst-case scenario by delineating the rectum adjacent to the prostate. However, a planning study would have to prove whether this is feasible without compromising on target coverage.

We observed an increase in bladder dose of around 25% between CT1 and follow-up CTs. Despite this increase, only in one case the tolerance dose of 144 cGy per pulse (120% of the PD) was exceeded. Foster reported a nonsignificant decrease in bladder dose on day two, which is probably due to caudal displacement of catheters [15], as reported by others [29]. The increase found in our data was unexpected. Since all patients had a transurethral catheter in place, we have not analysed bladder volumes and the distance between prostate and bladder surfaces. Besides, the interface between bladder and prostate is difficult to visualise on CT [22,23], making dosimetry less reliable. Variations in bladder dose can be attributed to intra-observer differences in bladder delineation. It is therefore uncertain if there was an actual increase in bladder dose during the 48 hour treatment. Because of this delineation variability and lack of consistency in bladder filling throughout regular (EBRT) treatments, (planning) DVH parameters do not represent the actually delivered doses well. This explains why only a few publications exist in which a dose–effect relationship could be established [30-32]. The clinical implications of any possible increase in dose to the bladder are therefore unknown.

The originally planned urethral dose was slightly lower on the repeat CTs, which led to a decrease in patients exceeding the tolerance dose. Others reported an increase in urethral dose [16,17,29], whereas Foster did not observe a significant difference in a group of 15 patients [15]. Kovalchuk et al. observed no change but an increasing range of dose to the urethra after 6 hours (with the improvement after replanning being insignificant) [14]. Although our decrease was statistically significant, it must be noted that the dose to 0.1 cm$^3$ of the urethra is sensitive to minor changes in delineation and catheter reconstruction, due to the large dose gradients in the centre of the target volume.

### 3.6 Conclusions

During the 48 hours after implantation, in which PDR brachytherapy treatment takes place, target coverage ($V_{100\%}$) and dose to the prostate ($D_{90}$) do not show large deviations from the planned values. However, bladder and rectum doses are subject to variation and were generally lower during planning than on the repeat CTs. Especially for the rectum, an increase in the dose during treatment should therefore be taken into
Deviations from the planned dose account during treatment planning, if possible by adding a margin or taking the worst-case scenario.

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3.7 References


[10] Steenbakkers RJ, Deurloo KE, Nowak


