Original paper

Robustness of IPSA optimized high-dose-rate prostate brachytherapy treatment plans to catheter displacements

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Abstract

Purpose: Inverse planning simulated annealing (IPSA) optimized brachytherapy treatment plans are characterized with large isolated dwell times at the first or last dwell position of each catheter. The potential of catheter shifts relative to the target and organs at risk in these plans may lead to a more significant change in delivered dose to the volumes of interest relative to plans with more uniform dwell times.

Material and methods: This study aims to determine if the Nucletron Oncentra dwell time deviation constraint (DTDC) parameter can be optimized to improve the robustness of high-dose-rate (HDR) prostate brachytherapy plans to catheter displacements. A set of 10 clinically acceptable prostate plans were re-optimized with a DTDC parameter of 0 and 0.4. For each plan, catheter displacements of 3, 7, and 14 mm were retrospectively applied and the change in dose volume histogram (DVH) indices and conformity indices analyzed.

Results: The robustness of clinically acceptable prostate plans to catheter displacements in the caudal direction was found to be dependent on the DTDC parameter. A DTDC value of 0 improves the robustness of planning target volume (PTV) coverage to catheter displacements, whereas a DTDC value of 0.4 improves the robustness of the plans to changes in hotspots.

Conclusions: The results indicate that if used in conjunction with a pre-treatment catheter displacement correction protocol and a tolerance of 3 mm, a DTDC value of 0.4 may produce clinically superior plans. However, the effect of the DTDC parameter in plan robustness was not observed to be as strong as initially suspected.

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Key words: brachytherapy, catheter displacement, DTDC, IPSA, prostate cancer.

Purpose

Prostate cancer is the most common male malignancy in the Western world, and as life expectancy increase, the prevalence is also expected to increase in an aging population [1]. Radiotherapy is an important therapeutic modality for the treatment of patients with localized or locally advanced prostate cancer [2] utilizing both external beam radiotherapy (EBRT) and brachytherapy. Over the last few decades, significant advances in technology related to high-dose-rate (HDR) brachytherapy have seen an increase in its use as a localized boost to EBRT of the prostate.

An important technological advancement in HDR brachytherapy is the evolution from forward planning to inverse planning techniques [3,4,5]. The inverse planning optimization algorithm currently implemented in the Nucletron Oncentra (Nucletron B.V., Veenendaal, The Netherlands) brachytherapy treatment planning system (TPS) is the inverse planning simulated annealing (IPSA) optimization algorithm. Inverse planning simulated annealing is based on contoured anatomy and optimizes dwell times using a simulated annealing algorithm [6]. The algorithm is constrained by user specific surface and volumetric dose constraints for both the target volume and organs at risk to calculate clinically acceptable treatment plans [7].

Inverse planning simulated annealing optimized brachytherapy treatment plans are characterized with large isolated dwell times at the first or last dwell position of each catheter. The central dwell positions however consist of extremely short, or zero, dwell times [8]. There is concern amongst users that these large isolated dwell times may lead to hot spots, either inside or outside the target. Also, the potential of catheter shifts relative to

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the target and organs at risk may lead to a more significant change in delivered dose to the volumes of interest relative to plans with more uniform dwell times. Recently, the Nucletron Oncentra TPS has added the dwell time deviation constraint (DTDC) parameter to the IPSA optimization process. This parameter constrains the allowable dwell times in the optimization process and can be set to a value between 0 and 1 in increments of 0.1. A value of 0 corresponds to completely unrestricted dwell times and a value of 1 results in homogeneous dwell times [9].

The displacement of catheters relative to the target and organs at risk during the time between imaging and patient treatment has been reported by a number of groups [10,11,12,13]. The displacements have predominantly been reported along the patient longitudinal axis and in the caudal direction [10] primarily due to acute edema between the prostate and perineal skin [14]. Previous work from our group [11] demonstrated a median catheter displacement of 7.5 mm in caudal direction (range 2.9-23.9 mm) in the time from planning CT to treatment (approximately 1-3 hours). Tiong *et al*. [10] have reported significant adverse effects on the tumor control probability for catheter displacements larger than 3 mm, including underdosage of the target and overdosage to critical structures. Due to these findings, our department has implemented a clinical protocol, in which internal catheter positions are verified and corrected immediately prior to treatment delivery with a tolerance of 3 mm.

This study aims to determine if the DTDC parameter can be optimized to improve the robustness of HDR prostate brachytherapy plans to catheter displacements relative to patient anatomy. A set of 10 clinically acceptable prostate plans were re-optimized with a DTDC parameter of 0 and 0.4. The values of 0 and 0.4 were chosen to reflect the change that is currently occurring in our clinical protocol. For each plan, catheter displacements of 3, 7, and 14 mm were retrospectively applied, and the change in DVH indices and conformity indices analyzed.

Material and methods

Initial plans

A set of 10 clinical prostate HDR brachytherapy plans were chosen for analysis. These CT plans were created between 2012 and 2015 on the Nucletron Oncentra Brachytherapy TPS (v4.3, Nucletron B.V., Veenendaal, The Netherlands). The prostate planning target volume (PTV), urethra, and rectum were all contoured by the same radiation oncologist at the time of treatment. Prostate volumes varied between 25.1 and 59.4 cm^3 and the number of catheters used was between 14 and 24. All patients received 2 fractions of 9.5 Gy with 2 weeks between fractions. Catheter insertion (using Oncosmart, ProGuide Sharp Needle, 6F, Nucletron B.V., Veenendaal, The Netherlands), CT scan, planning, and treatment are all performed on the same day, and the mean time between the planning CT and treatment was 182 minutes.

IPSA optimization and DTDC

Each plan was optimized using the IPSA algorithm using the parameters outlined in Table 1. As per clinical protocol, plans were initially optimized with the DTDC parameter set to 0. The plans were then re-optimized with the DTDC parameter set to 0.4 and all other parameters kept constant. The dwell time characteristics of each plan were then compared using the plan modulation index (M), as defined by Smith *et al*. [9]. The plan modulation index is defined as the maximum deviation of dwell time from the average dwell time for each catheter, normalized to the maximum dwell time for the treatment plan, averaged over all catheters in the plan.

Catheter displacements

Catheter displacements in the caudal direction were then simulated for each plan. Offsets of 3, 7, and 14 mm were performed. Displacements of this magnitude were chosen as they corresponded to clinically relevant catheter displacements, as found in a previous study by our group [11]. Our center has implemented a clinical protocol, in which catheter displacements ≥ 3 mm are corrected for, immediately prior to treatment by altering the indexer length at the treatment console. Implanting the catheters past the prostate base into the bladder allowed for extra dwell positions beyond the prostate in the event of a caudal shift. Physical re-insertion was not performed.

Plan analysis

All patient plans were assessed by evaluating dose volume histogram (DVH) indices and dose quality indices. Dose volume histogram indices used for plan evaluation are outlined in Table 2. Furthermore, a normal tissue (NT) contour was created by adding a 2 mm margin around the PTV and subtracting this expanded contour from the external contour, e.g. NT = Body – (PTV + 2 mm). These parameters were automatically calculated by the

Table 1. Inverse planning simulated annealing (IPSA) optimization parameters used for patient plan optimization

ROI	Usage	Surface				Volume			
		Weight	Min (cGy)	Max (cGy)	Weight	Weight	Min (cGy)	Max (cGy)	Weight
Prostate	PTV	100	950	1425	100	100	100	950	30
Rectum	Organ			665	50	50		475	50
Urethra	Organ	120	950	998	50	50	950	998	50

PTV – planning target volume

TPS and are highly dependent on the size of the histogram bin used for calculation [8]. Because of this, a conformity index (CI), a dose inhomogeneity index (DHI), and an overdose volume index (ODI) were also calculated for each plan.

The CI used in this study is the one introduced by van't Riet *et al*. [15] and is shown in Equation 1:

$$CI = \frac{V_{T,ref}}{V_T} \times \frac{V_{T,ref}}{V_{ref}} \quad (1),$$

where $V_{T,ref}$ is the volume of the PTV receiving a dose greater than or equal to the 100% isodose, V_T is the volume of the PTV, and V_{ref} is the volume of the 100% isodose. The DHI parameter gives an indication of the homogeneity of the dose within the PTV, which was first introduced by Wu *et al*. [16] and is shown in Equation 2:

$$DHI = \frac{V_{T,ref} - V_{T,1.5ref}}{V_{T,ref}} \quad (2),$$

where $V_{T,1.5ref}$ is the volume of the PTV receiving a dose greater than or equal to the 150% isodose, and $V_{T,ref}$ is as described above. Finally, the ODI parameter [17] indicates the amount of high dose (greater than 200%) within the PTV:

$$ODI = \frac{V_{T,2ref}}{V_{T,ref}} \quad (3),$$

where $V_{T,2ref}$ is the volume of the PTV receiving a dose greater than or equal to the 200% isodose.

The change in DVH and dose quality indices was then calculated as a function of catheter displacement for both DTDC values of 0 and 0.4. The change in these indices with increasing catheter displacement gives an indication of the robustness of the plans to changes in catheter position relative to the targets and organs at risk between planning CT and treatment. Statistical significance between the DTDC values was verified using a paired *t*-test with $\alpha = 0.05$ (corresponding to a 5% significance level).

Table 3. Plan modulation index (M) and normalized total dwell time ($cGy^{-1}cm^{-2}$)

Patient	Plan modulation index (M)		Normalized total dwell time ($cGy^{-1}cm^{-2}$)	
	DTDC 0	DTDC 0.4	DTDC 0	DTDC 0.4
1	0.48	0.09	8.32×10^{-6}	7.73×10^{-6}
2	0.34	0.23	2.75×10^{-6}	2.55×10^{-6}
3	0.43	0.25	2.57×10^{-6}	2.33×10^{-6}
4	0.41	0.23	10.44×10^{-6}	9.82×10^{-6}
5	0.57	0.17	15.27×10^{-6}	14.32×10^{-6}
6	0.43	0.18	12.45×10^{-6}	12.34×10^{-6}
7	0.42	0.24	6.32×10^{-6}	6.12×10^{-6}
8	0.48	0.19	8.72×10^{-6}	8.29×10^{-6}
9	0.40	0.21	8.37×10^{-6}	7.80×10^{-6}
10	0.44	0.20	7.27×10^{-6}	6.80×10^{-6}

DTDC – dwell time deviation constraint

Table 2. Clinically acceptable dose volume histogram (DVH) indices

Volume type	Dose (%)	Dose (cGy)	Volume (%)
PTV	100	950	≥ 90
PTV	150	1425	< 30
PTV	200	1900	< 15
Rectum	70	665	0
Urethra	120	1140	0

PTV – planning target volume

Results

Initial clinical plans

Initial clinical prostate plans IPSA optimized with a DTDC value of 0 produced a large spread of dwell times, relative to those plans optimized with a DTDC value of 0.4. The plan modulation index (M) for each plan variant is given in Table 3 along with the total dwell time, normalized to the air kerma strength of the source. The average M for the 0 DTDC case (± 1 SD) was equal to 0.44 ± 0.07, whereas for the 0.4 DTDC case M = 0.20 ± 0.06. The effect of increasing the DTDC parameter is to limit the maximum dwell time in any catheter; this is reflected by the decreasing value of M, as more homogeneous dwell time distribution is created within each cath-

Table 4. Initial dose volume histogram (DVH) and dose indices before catheter displacement

Parameter	DTDC 0	DTDC 0.4	*p*
PTV $V_{100\%}$	92.9 ± 1.9%	93.4 ± 1.7%	≤ 0.2620
PTV $V_{150\%}$	18.9 ± 3.6%	23.0 ± 3.7%	≤ 0.0001
PTV $V_{200\%}$	7.5 ± 1.6%	9.0 ± 1.4%	≤ 0.0002
Rectum $V_{70\%}$	0.1 ± 0.1%	0.1 ± 0.1%	≤ 0.3498
Urethra $V_{120\%}$	10.4 ± 5.6%	5.9 ± 5.9%	≤ 0.0421
NT $V_{100\%}$	11.0 ± 3.0 cc	5.7 ± 1.9 cc	≤ 0.0001
NT $V_{150\%}$	3.3 ± 1.4 cc	1.2 ± 0.7 cc	≤ 0.0001
NT $V_{200\%}$	1.5 ± 0.2 cc	0.5 ± 0.3 cc	≤ 0.0018
CI	0.691 ± 0.046	0.748 ± 0.042	≤ 0.0002
DHI	0.204 ± 0.039	0.246 ± 0.038	≤ 0.0001
ODI	0.081 ± 0.018	0.097 ± 0.014	≤ 0.0004

PTV – planning target volume, NT – normal tissue, CI – conformity index, DHI – dose inhomogeneity index, ODI – overdose index, $V_{100\%}$, $V_{150\%}$, $V_{200\%}$, $V_{70\%}$, $V_{120\%}$ – volume of relevant structure receiving 100%, 150%, 200%, 70%, and 120% of the prescribed isodose, respectively, DTDC – dwell time deviation constraint

Table 5. Change in dose volume histogram (DVH) and dose indices for a 3 mm catheter displacement

Parameter	DTDC 0	DTDC 0.4	*p*
PTV $V_{100\%}$	0.788 ± 0.751%	–1.299 ± 0.916%	≤ 0.0001
PTV $V_{150\%}$	1.786 ± 1.540%	0.146 ± 0.537%	≤ 0.0009
PTV $V_{200\%}$	1.051 ± 0.829%	–0.034 ± 0.183%	≤ 0.0021
Rectum $V_{70\%}$	0.078 ± 0.081%	0.080 ± 0.090%	≤ 0.8905
Urethra $V_{120\%}$	–5.628 ± 4.878%	–4.019 ± 5.047%	≤ 0.0088
NT $V_{100\%}$	–1.042 ± 1.314 cc	1.314 ± 1.661 cc	≤ 0.0454
NT $V_{150\%}$	–1.033 ± 0.893 cc	0.468 ± 0.504 cc	≤ 0.0001
NT $V_{200\%}$	–0.568 ± 0.674 cc	0.171 ± 0.318 cc	≤ 0.0052
CI	0.002 ± 0.017	–0.024 ± 0.022	≤ 0.0011
DHI	0.017 ± 0.005	0.005 ± 0.006	≤ 0.0033
ODI	0.011 ± 0.008	0.001 ± 0.002	≤ 0.0035

PTV – planning target volume, NT – normal tissue, CI – conformity index, DHI – dose inhomogeneity index, ODI – overdose index, $V_{100\%}$, $V_{150\%}$, $V_{200\%}$, $V_{70\%}$, $V_{120\%}$ – volume of relevant structure receiving 100%, 150%, 200%, 70%, and 120% of the prescribed isodose, respectively, DTDC – dwell time deviation constraint

eter. The total dwell time, normalized to the air kerma strength of the source was also seen to decrease for plans optimized with a DTDC value of 0.4, relative to a DTDC of 0. This is due to the reduction in large isolated dwell times at the first or last dwell positions of each catheter.

Table 4 shows the change in DVH and dose quality indices when re-optimizing the plans with a DTDC parameter of 0.4. By changing the DTDC value to 0.4, the coverage of the PTV is improved, as reflected by the increase in PTV $V_{100\%}$ and CI, however, only the difference in CI was found to be statistically significant. Statistically significant reductions in NT $V_{100\%}$, NT $V_{150\%}$, and NT $V_{200\%}$ were also found when changing DTDC from 0 to 0.4. This, along with the improvement in CI, is due to the reduction in the large isolated dwell times just outside of the PTV, which are delivering higher doses to the adjacent healthy tissue. On the other hand, there is a statistically significant increase in PTV $V_{150\%}$, PTV $V_{200\%}$, DHI, and ODI for DTDC 0.4 versus DTDC 0. The rectum $V_{150\%}$ was largely unaffected by the DTDC change, and a small reduction in the urethra $V_{120\%}$ was observed.

Effect of catheter displacements

The effect of catheter displacements on DVH and dose quality indices are shown in Tables 5, 6, and 7 for catheter shifts of 3, 7, and 14 mm, respectively. Overall, a DTDC value of 0 improves the robustness of PTV coverage to catheter displacements relative to a DTDC value of 0.4. This is reflected in the smaller changes in PTV $V_{100\%}$ (Figure 1) and CI (Figure 2) for all three catheter displacement values. The dwell positions moving out of the PTV in the DTDC 0 plans have smaller weights relative to those in the DTDC 0.4 plans, resulting in smaller changes in PTV $V_{100\%}$ and CI with catheter displacement.

Conversely, a DTDC value of 0.4 improves the robustness of the plans to changes in hotspots, reflected by statistically significant differences in changes to PTV $V_{150\%}$, PTV $V_{200\%}$ (Figure 3), DHI, and ODI (Figure 4) compared to plans optimized with a DTDC value of 0 for catheter displacements up to 14 mm. This behavior can be explained by considering that the isolated dwell times at the end of the catheters often exist just outside the PTV be-

Table 6. Change in dose volume histogram (DVH) and dose indices for a 7 mm catheter displacement

Parameter	DTDC 0	DTDC 0.4	*p*
PTV $V_{100\%}$	–2.803 ± 2.516%	–8.99 ± 2.283%	≤ 0.0001
PTV $V_{150\%}$	2.199 ± 2.670%	–1.262 ± 1.158%	≤ 0.0002
PTV $V_{200\%}$	1.255 ± 1.260%	–0.689 ± 0.427%	≤ 0.0008
Rectum $V_{70\%}$	0.271 ± 0.324%	0.265 ± 0.324%	≤ 0.7793
Urethra $V_{120\%}$	–6.461 ± 5.879%	–4.333 ± 6.804%	≤ 0.0205
NT $V_{100\%}$	1.072 ± 3.121 cc	4.381 ± 1.996 cc	≤ 0.0189
NT $V_{150\%}$	–0.399 ± 1.639 cc	1.507 ± 0.753 cc	≤ 0.0041
NT $V_{200\%}$	–0.471 ± 0.940 cc	0.641 ± 0.517 cc	≤ 0.0014
CI	–0.046 ± 0.044	–0.136 ± 0.046	≤ 0.0005
DHI	0.029 ± 0.024	0.011 ± 0.016	≤ 0.0007
ODI	0.016 ± 0.012	0.002 ± 0.004	≤ 0.0020

PTV – planning target volume, NT – normal tissue, CI – conformity index, DHI – dose inhomogeneity index, ODI – overdose index, $V_{100\%}$, $V_{150\%}$, $V_{200\%}$, $V_{70\%}$, $V_{120\%}$ – volume of relevant structure receiving 100%, 150%, 200%, 70%, and 120% of the prescribed isodose, respectively, DTDC – dwell time deviation constraint

Table 7. Change in dose volume histogram (DVH) and dose indices for a 14 mm catheter displacement

Parameter	DTDC 0	DTDC 0.4	*p*
PTV $V_{100\%}$	–18.69 ± 5.197%	–25.74 ± 5.313%	≤ 0.0003
PTV $V_{150\%}$	0.522 ± 3.343%	–3.589 ± 2.063%	≤ 0.0001
PTV $V_{200\%}$	0.566 ± 1.455%	–1.628 ± 0.786%	≤ 0.0005
Rectum $V_{70\%}$	0.690 ± 0.917%	0.665 ± 0.956%	≤ 0.4049
Urethra $V_{120\%}$	–4.657 ± 7.543%	–0.592 ± 10.624%	≤ 0.0523
NT $V_{100\%}$	8.928 ± 4.198 cc	13.495 ± 2.333 cc	≤ 0.0002
NT $V_{150\%}$	1.582 ± 1.210 cc	3.981 ± 1.197 cc	≤ 0.0008
NT $V_{200\%}$	0.453 ± 0.786 cc	1.756 ± 0.747 cc	≤ 0.0036
CI	–0.251 ± 0.072	–0.352 ± 0.064	≤ 0.0003
DHI	0.056 ± 0.040	0.041 ± 0.039	≤ 0.0013
ODI	0.027 ± 0.018	0.013 ± 0.010	≤ 0.0043

PTV – planning target volume, NT – normal tissue, CI – conformity index, DHI – dose inhomogeneity index, ODI – overdose index, $V_{100\%}$, $V_{150\%}$, $V_{200\%}$, $V_{70\%}$, $V_{120\%}$ – volume of relevant structure receiving 100%, 150%, 200%, 70%, and 120% of the prescribed isodose, respectively, DTDC – dwell time deviation constraint

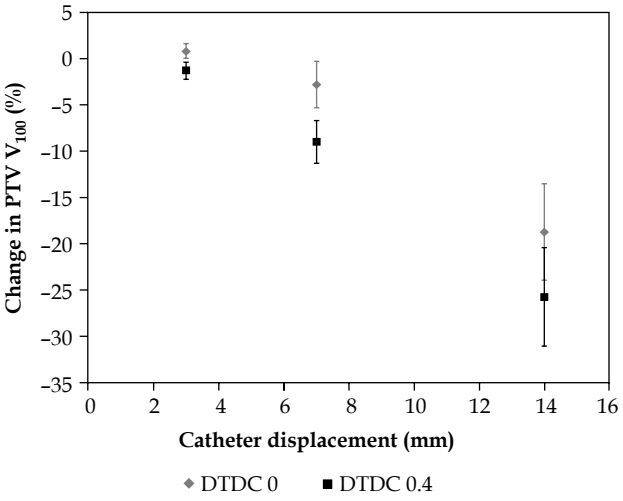

Fig. 1. The change in PTV $V_{100\%}$ as a function of catheter displacement for plans optimized with DTDC set to 0 and 0.4 (error bars showing 95% confidence interval)

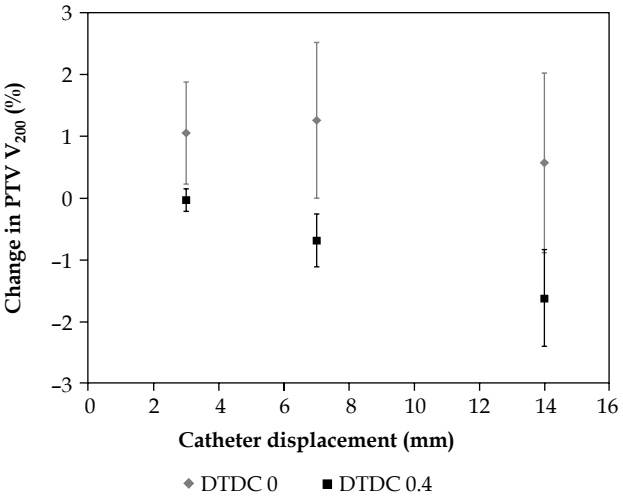

Fig. 2. The change in PTV $V_{200\%}$ as a function of catheter displacement for plans optimized with DTDC set to 0 and 0.4 (error bars showing 95% confidence interval)

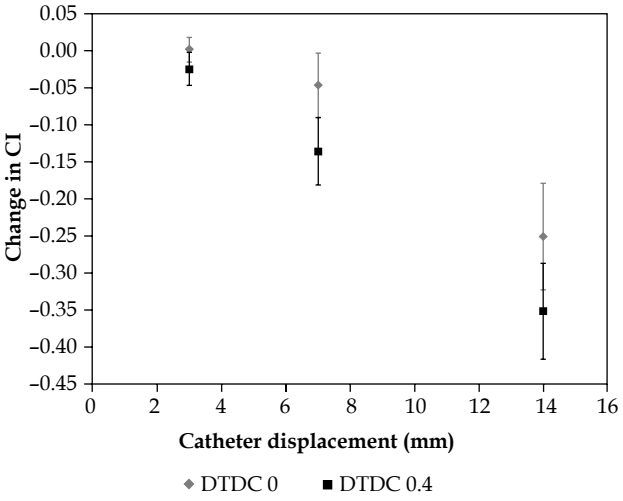

Fig. 3. The change in CI as a function of catheter displacement for plans optimized with DTDC set to 0 and 0.4 (error bars showing 95% confidence interval)

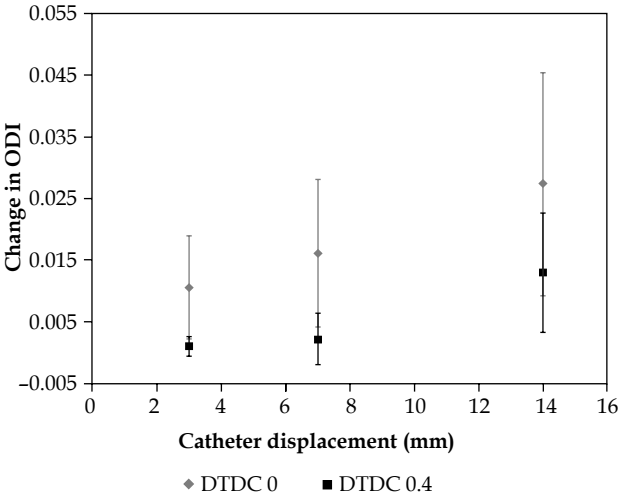

Fig. 4. The change in ODI as a function of catheter displacement for plans optimized with DTDC set to 0 and 0.4 (error bars showing 95% confidence interval)

fore a catheter shift is implemented. Therefore, the $V_{150\%}$ and $V_{200\%}$ volumes are surrounding these dwell positions and, as a catheter shift is implemented, they move further away from the PTV and into healthy tissue.

For a catheter displacement of 3 mm, plans optimized with a DTDC value of 0.4 were found to be more robust in terms of NT $V_{100\%}$, NT $V_{150\%}$, and NT $V_{200\%}$. Conversely, for larger catheter shifts of 7 and 14 mm, the plans optimized with DTDC 0 were more robust. This is due to the fact that for a catheter shift of 3 mm, one of the large isolated dwell positions in the DTDC 0 plans moves into the normal tissue. However, for larger shifts, subsequent dwell positions moving into the normal tissue have significantly smaller dwell times compared to those in the DTDC 0.4 plans, resulting in smaller changes in NT $V_{100\%}$, NT $V_{150\%}$, and NT $V_{200\%}$.

The urethra $V_{120\%}$ was more sensitive to catheter displacements than the rectum $V_{70\%}$ for both values of DTDC. A DTDC value of 0.4 improved the robustness of the plans to changes in urethra $V_{120\%}$ compared to plans optimized with a DTDC value of 0, with statistically significant differences for catheter displacements of 3 and 7 mm. There was also no statistically significant difference found between DTDC values for the rectum $V_{70\%}$.

Discussion

As expected, the plan modulation index (M) was observed to decrease with an increased value of DTDC. The calculated values of M = 0.44 ± 0.07 (DTDC = 0) and M = 0.20 ± 0.06 (DTDC = 0.4) are in close agreement with those found in a previous study by Smith *et al.* [9]. The in-

crease value of DTDC was also observed to increase the PTV $V_{100\%}$, $V_{150\%}$, and $V_{200\%}$. The increase in PTV $V_{150\%}$ of 4% and PTV $V_{200\%}$ of 1.5% when changing the DTDC value from 0 to 0.4 was also observed in the same study [9]. This increase resulted in DVH indices that were still clinically acceptable for treatment according to our local protocol as outlined in Table 2.

Contrary to expectation, the DTDC value of 0 produced plans that were more robust to catheter displacements in terms of target coverage. However, for a catheter displacement of 3 mm, the average CI was 0.693 ± 0.049 and 0.723 ± 0.045 for DTDC = 0 and DTDC = 0.4, respectively. Our center has implemented a clinical protocol, in which catheter displacements ≥ 3 mm are corrected for, immediately prior to treatment by adjusting the indexer length on the treatment control system. Therefore, if used in combination with this catheter correction protocol, plans optimized with a DTDC value of 0.4 may be clinically superior to those optimized with DTDC = 0, especially when considering that using a DTDC value of 0.4 improves robustness to changes in hotspots and dose to OARs and healthy tissue.

One recent advance in the field of HDR prostate brachytherapy has been the use of 3D trans-rectal ultrasound (TRUS) based treatment planning [18]. The use of this technique has been shown to significantly reduce the time between imaging and treatment compared to CT based treatment planning. Milickovic *et al*. [18] have shown that for an average time between imaging and treatment of 51.2 minutes, the average needle displacement was found to be 1 mm. This displacement is small relative to those noted in other studies [11,14], and is likely due to the reduction in time between imaging and treatment. Therefore, one current initiative of our group is to reduce the time between imaging and treatment, and the introduction of 3D TRUS based planning is being investigated.

A previous study by our group [11] has shown that catheter displacements in the cranial direction occurred for only 3 of 48 cases, with the remainder occurring in the caudal direction. One limitation of this study is that catheter displacements were only considered along the longitudinal axis in the caudal direction. Catheter shifts in the lateral and anterior-posterior directions due to edema were also not considered.

A further limitation is that only two values of DTDC were considered. Preliminary calculations showed that small changes in DTDC, e.g. from 0.2-0.4 do not significantly affect the robustness of the plans to catheter displacements. Furthermore, values of 0 and 0.4 were chosen to reflect the change that is currently occurring in our clinical protocol. Historically, plans have been optimized using a DTDC value of 0; however previous studies [9] have shown that a DTDC value of 0.4 gives plan modulation equivalent to graphical optimization without significantly compromising plan quality.

Conclusions

The results of this study indicate that the robustness of clinically acceptable prostate plans to catheter displacements in the caudal direction are dependent on the DTDC parameter. A DTDC value of 0 improves the robustness of PTV coverage to catheter displacements relative to a DTDC value of 0.4. Whereas a DTDC value of 0.4 improves the robustness of the plans to changes in hotspots compared to a DTDC value of 0. For a catheter displacement of 3 mm, plans optimized with a DTDC value of 0.4 were found to be more robust in terms of the dose to normal tissue. However, for larger catheter shifts, the plans optimized with DTDC 0 were more robust, due to larger shifts moving relatively small weight dwell positions into the normal tissue compared to the DTDC 0.4 plans. When used in combination with a pre-treatment catheter displacement correction protocol and a tolerance of 3 mm, a DTDC value of 0.4 may produce clinically superior plans.

In future work, attempts will be made to measure the actual dwell times delivered by the afterloader as compared to those calculated by the TPS for a range of DTDC values and the effect on the dose examined.

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Disclosure

Authors report no conflict of interest.

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