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Effectiveness of Rotating Shield Brachytherapy for Prostate Cancer Dose Escalation and Urethral Sparing

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Abstract

Purpose: To compare single-fraction ¹⁵³Gd-based rotating shield brachytherapy (RSBT) for prostate cancer to conventional ¹⁹²Ir-based high-dose-rate brachytherapy (HDR-BT) in a planning study which radiobiologically accounts for dose rate and relative biological effectiveness (RBE). RSBT was used for planning target volume (PTV) dose escalation without increasing urethral dose for monotherapy, or for urethral sparing without decreasing PTV dose as a boost to external beam radiotherapy.

Methods: Twenty-six patients were studied. PTV doses were expressed as equivalent dose delivered in 2 Gy fractions (EQD2), accounting for RBE (1.00 for ¹⁹²Ir and 1.15 for ¹⁵³Gd), dose protraction (114 minute repair half-time), and tumor dose response (α/β of 3.41 Gy). HDR-BT dose was prescribed such that 90% of the PTV received 110% of the prescription dose of 19 Gy for dose escalation and 15 Gy for urethral sparing, corresponding to EQD2_{90%} values (minimum EQD2 to the hottest 90% of the PTV) of 93.9 Gy_{EQD2} and 60.7 Gy_{EQD2}, respectively. Twenty 90.95 GBq ¹⁵³Gd RSBT sources were modeled and one 370 GBq ¹⁹²Ir HDR-BT source.

Results: For dose escalation with fresh sources, RSBT increased PTV EQD2_{90%} by 42.5% $\pm$ 8.4% (average $\pm$ standard deviation) without increasing urethral $D_{10\%}$, with treatment times of 216.8 $\pm$ 28.9 minutes versus 15.1 $\pm$ 2.1 minutes. After one half-life (240.4 days for ¹⁵³Gd and 73.8 days for ¹⁹²Ir), EQD2_{90%} increased 20.5% $\pm$ 9.1%. For urethral sparing with fresh sources, RSBT decreased urethral $D_{10\%}$ by 26.0% $\pm$ 3.4% without decreasing PTV EQD2_{90%}, with treatment

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times of 133.6 ± 16.5 minutes versus 12.0 ± 1.7 minutes. After one half-life, urethral $D_{10\%}$ decreased $20.2\% \pm 4.8\%$.

Conclusion: RSBT can increase PTV EQD_{90%} or decrease urethral $D_{10\%}$ relative to HDR-BT at the cost of increased treatment time. Source aging reduces RSBT benefit, but RSBT remains theoretically superior to HDR-BT by >20% after one-half-life has elapsed.

Keywords

Brachytherapy; rotating shield brachytherapy; intensity modulated brachytherapy; prostate cancer; multisource brachytherapy; brachytherapy dose protraction

I. INTRODUCTION

Localized prostate cancer patients have many treatment options including surgical resection with radical prostatectomy [1], external beam radiotherapy (EBRT) alone [2], external beam radiotherapy combined with brachytherapy [3], low-dose-rate brachytherapy (LDR-BT) [4], high-dose-rate brachytherapy (HDR-BT) [5], stereotactic body radiation therapy [6], chemotherapy [7], and active surveillance [8]. Androgen deprivation therapy is often used in conjunction with many of these options [7]. Regardless of the treatment option chosen, 5-year relative survival rates are typically above 90% [9]. Given the high survival rate, the anticipated complications from treatment are an important concern as patients may live with them for decades. One treatment option for localized prostate cancer that has the potential for reducing complication rates while maintaining effective disease control is HDR-BT. However, the emergence of HDR-BT in different treatment regimens has revealed unresolved limitations, especially when used in conjunction with EBRT. One of these limitations is the rate of genitourinary (GU) toxicity, which has been found to be significantly higher than rates reported with other treatment techniques, such as EBRT alone [3,10,11]. Trials of combined EBRT and HDR-BT therapy have reported correlations between urethra $D_{10\%}$ (the minimum dose to the hottest 10% of the urethra) and an increased risk of Grade 2 or higher GU toxicity, as well as decreasing EPIC urinary domain score [3,11,12].

Rotating shield brachytherapy (RSBT) is a technique proposed to reduce the rates of GU toxicity for patients receiving an HDR-BT boost as well as permit dose escalation in HDR-BT monotherapy [13]. Compared to the radially symmetric dose distributions produced by high energy sources such as ^{192}Ir , the lower energy of ^{153}Gd allows partial shielding to produce an asymmetric dose distribution [14,15]. The ^{153}Gd sources have a lower dose rate than ^{192}Ir and a multisource system was proposed by Dadkhah et al [16] to enable clinical delivery. With a multisource apparatus, dose delivery can be optimized to avoid sensitive healthy tissue and provide a highly conformal dose distribution to the targeted area. In a previous study, RSBT was shown to theoretically reduce urethral dose by 29–44% relative to conventional HDR-BT [13], depending on the size of a 0–5 mm margin around the urethra for the dose gradient. However, this study was limited to a single patient and did not account for radiobiological changes in dose rate or relative biological effectiveness (RBE).

The purpose of this work is to evaluate the effectiveness of RSBT in a multi-patient planning study for both urethral sparing, simulating RSBT as a boost to external beam radiotherapy, and dose escalation, simulating RSBT as monotherapy. Recent trials with HDR-BT as monotherapy using a prescription dose of 19–20 Gy given in one fraction have reported low grade 3 or higher toxicities of 0–2% [17–21]. However, the long-term biochemical relapse free survival in these studies varied from 66–98.6% [17–22]. The connection between dose escalation and improved outcomes with prostate cancer is well known [23], but further escalation is currently limited by urethral dose constraints [18]. If the dose to the planning target volume (PTV) could be increased without violating urethral dose constraints, it is possible long-term biochemical relapse free survival rates could be improved while maintaining low toxicity rates. In the dose escalation plan, RSBT dose gradients allow for significantly higher PTV increases without exceeding the urethral dose limits already in use clinically. The clinical feasibility of the RSBT approach was evaluated by modeling the radiobiological effectiveness of RSBT after sources have aged one half-life (240.4 days for ^{153}Gd and 73.8 days for ^{192}Ir).

II. MATERIALS AND METHODS

Treatment plans of 26 prostate cancer patients treated with conventional HDR-BT were obtained with Institutional Review Board approval and anonymized. Catheters were implanted under transrectal ultrasound (TRUS) guidance and computed tomography images were used in the treatment planning process. The PTV was defined as the entire volume of the prostate with no additional margin added [24]. A margin of 3 mm was added to the urethra contour to provide a dose gradient about the urethra. The mean ROI volumes (and ranges) for the PTV, urethra, bladder, and rectum were, respectively, $61.7 \pm 14.3 \text{ cm}^3$ (range: $41.1\text{--}89.3 \text{ cm}^3$), $2.2 \pm 0.7 \text{ cm}^3$ (range: $1.4\text{--}4.3 \text{ cm}^3$), $60.6 \pm 28.7 \text{ cm}^3$ (range: $25.3\text{--}129.0 \text{ cm}^3$), and $42.1 \pm 14.9 \text{ cm}^3$ (range: $22.2\text{--}87.6 \text{ cm}^3$). The variation in patient anatomy with respect to PTV volume is demonstrated in Table I.

The clinically-used catheter positions were used to generate the HDR-BT plans. For each patient, RSBT specific catheter positions were defined in a treatment planning system (BrachyVision[®], version 13.6, Varian Medical Systems, Inc. Palo Alto, CA). The median number of needles used for the HDR-BT plans was 23 (range: 20–24). The number of needles used for all patients in the RSBT plans was 20, as that is the needle capacity of the proposed RSBT device. In the RSBT plans, to use the dose gradients enabled by RSBT, catheters were placed in a ring abutting the urethra gradient margin, in a ring around the outer edge of the PTV, and in a uniform manner in the remaining area of the PTV (Figure 1). Twenty $91.0 \text{ GBq } ^{153}\text{Gd}$ sources were modeled as ^{153}Gd in Gd_2O_3 with an activity of 2,442 GBq of ^{153}Gd per gram of Gd_2O_3 [14,25,26]. The ^{192}Ir source was modeled after the VariSource (Varian Medical Solution, Inc., Palo Alto, CA) with an activity of 370 GBq.

When considering treatment planning for the rectum, Prada *et al.* [20] showed that the injection of hyaluronic acid into the anterior perirectal fat is a safe and well-tolerated procedure that reduces the total dose received by the rectal wall by increasing the distance between the rectum and prostate. This injection procedure was simulated in the current study

by incorporating a maximum distance of 1.5 cm, which is consistent with distances used clinically [27,28], between the rectum and PTV during region of interest (ROI) modeling.

Physical dose was calculated using a previously described dose calculation and optimization method [13] with the optimization parameters in Table II.

Physical dose for the PTV was converted to equivalent dose in 2 Gy fractions (EQD2) using the following parameters: α/β ratio of 3.41 Gy [29,30], treatment repair half-time of 1.9 hours [31], and RBE ratio of 1.15 for the ^{153}Gd used for RSBT and 1.00 for the ^{192}Ir used for HDR-BT [32]. The EQD2 was calculated for each voxel in the PTV as [33–35]:

$$EQD2 = \frac{D\left(\frac{\alpha}{\beta}RBE + G[\dot{D}(t)]D\right)}{\left(\frac{\alpha}{\beta} + 2\right)}, \text{ and} \quad (1)$$

$$G[\dot{D}(t)] = \frac{2}{D^2} \int_{t_{\text{start}}}^{t_{\text{stop}}} dt \dot{D}(t) \int_{t_{\text{start}}}^t dt' \dot{D}(t') e^{-\mu(t-t')}, \quad (2)$$

Where $\int_{t_{\text{start}}}^{t_{\text{stop}}} dt \dot{D}(t)$ is the total dose delivered between t_{start} and t_{stop} , which are the times when brachytherapy starts and stops, respectively, $\dot{D}(t)$ is the dose rate delivered at time t , $\mu = \frac{\ln(2)}{T_r}$, T_r is the treatment repair half-time, and $G[\dot{D}(t)]$ is the unitless Lea-Catcheside

dose protraction factor. After accounting for the radiobiological effects of treatment time with EQD2, dose was converted back into physical dose (D) to represent the dose as if delivered at the same dose rate as HDR-BT for each voxel in the PTV as:

$$D = f_{EQD2 \rightarrow D}(EQD2) = \sqrt{\frac{EQD2}{G[\dot{D}(t)]} \left(\frac{\alpha}{\beta} + 2\right)} + \frac{1}{4} \left(\frac{\alpha}{\beta} RBE\right)^2 - \frac{1}{2} \left(\frac{\alpha}{\beta} RBE\right) \quad (3)$$

To model aged sources after one half-life, source dwell times from the plans generated with fresh sources were scaled by a factor of two to reflect the reduction in dose rate, and $\dot{D}(t)$ was scaled by a factor of one-half relative to its magnitude with fresh sources. G -values and EQD2 were then recalculated using these scaled dwell times for each voxel of the PTV.

For the dose escalation plans, HDR-BT dose was prescribed such that 90% of the PTV received 110% of the prescribed physical dose of 19 Gy, corresponding to 93.9 Gy_{EQD2} for a G -value of 1.00. The final RSBT plan was created by scaling the dwell times to maximize EQD2_{90%} without exceeding the urethra $D_{10\%}$ (the minimum dose to the hottest 10% of the urethra) from the HDR-BT plan.

For the urethra sparing plans, HDR-BT dose was prescribed such that 90% of the PTV received 110% of the prescribed physical dose of 15 Gy, corresponding to 60.7 Gy_{EQD2} for a

G -value of 1.00. The final RSBT plan was created by scaling the dwell times to minimize urethral $D_{10\%}$ while matching the PTV EQD2_{90%} from the HDR-BT plan.

For the dose escalation plans, the increase in PTV EQD2_{90%} compared to HDR-BT was the metric for RSBT improvement over HDR-BT as it reflects the magnitude of dose escalation to the PTV possible with RSBT. In the urethra sparing plan the decrease in urethra $D_{10\%}$ compared to HDR-BT was the metric for RSBT improvement as it reflects the reduction in dose to the urethra possible with RSBT.

For treatment planning criteria, an effective prescription dose ($D_{Rx_{eff}}$) was derived from PTV EQD2_{90%} after dose scaling, where:

$$D_{Rx_{eff}} = \frac{f_{EQD2 \rightarrow D(EQD2_{90\%})}}{1.1} \quad (4)$$

This effective prescription dose was converted to physical dose using Eq. 3. As a measure of homogeneity between treatment modalities, PTV V_{150} and V_{200} were calculated using effective prescription dose. As a measure of tumor coverage, PTV V_{100} was calculated using absolute prescription dose (19 Gy for dose escalation and 15 Gy for urethra sparing). Treatment planning criteria are shown in Table III [19,36]. Bladder and rectal dose criteria are the physical dose equivalents of 80 Gy_{EQD2} and 65 Gy_{EQD2}, respectively [34]. In the urethra sparing plan bladder dose criteria assumes 37.5 Gy in 15 fractions of 2.5 Gy has already delivered by EBRT [37], or the equivalent of 41.0 Gy_{EQD2}.

III. RESULTS

Table IV shows a comparison of the treatment planning results for HDR-BT versus RSBT in the two treatment plans, for fresh sources versus aged one half-life sources.

In the dose escalation plan the maximum increase in PTV EQD2_{90%} for RSBT over HDR-BT occurred with fresh RSBT sources and aged 1 half-life HDR-BT sources, and the reverse was true for the minimum increase. The ratio of the increase in RSBT PTV EQD2_{90%} compared to HDR-BT ranged from 42.5% to 20.5%, and there was no combination of ^{153}Gd and ^{192}Ir source ages where the PTV EQD2_{90%} was greater than for HDR-BT than for RSBT.

In the urethra sparing plan the maximum decrease in urethral $D_{10\%}$ for RSBT compared to HDR-BT occurred with fresh RSBT sources and aged 1 half-life HDR-BT sources, and the reverse was true for the minimum decrease. The ratio of the decrease in RSBT urethral $D_{10\%}$ compared to HDR-BT ranged from 26.0% to 20.2%, and there was no combination of ^{153}Gd and ^{192}Ir source ages where the HDR-BT urethral $D_{10\%}$ was less than RSBT. The metrics used to compare HDR-BT versus RSBT are in Table V.

The number of patients in the study who met treatment planning criteria requirements are shown in Table VI.

Dose distributions and dose-volume histograms for a representative patient are shown in Figure 1.

IV. DISCUSSION

The radiobiological properties of prostate cancer have important implications in determining the brachytherapy dose equivalent to external beam radiotherapy (EBRT). Determining the EQD2 delivered by EBRT allows a comparison of the potential effectiveness of brachytherapy treatment to that of EBRT [38]. Given that G -values have never been reported for every voxel in the PTV, our results represent a high level of precision as the calculated EQD2 distributions represent the radiobiological response of every voxel in the prostate to treatment. However, our EQD2 calculations are dependent upon several variables whose values are still debated in the literature, notably the α/β ratio and the treatment repair half-time (T_r). Our values for these two variables are based on publications in Nickers *et al*, Fowler *et al*, and Kal *et al* which considered the two parameters in context of each other, giving us our estimate of an α/β ratio of 3.41 Gy and T_r of 114 minutes [29–31]. The calculation of G -values and EQD2 require both the α/β ratio and T_r so if these values were discovered to be significantly different than our current values the results would be accordingly affected. For example, if T_r was found to be longer than currently thought, the relative biological effectiveness of RSBT would increase due to decreased tumor cellular repair during treatment delivery.

The treatment planning results for RSBT with fresh sources, compared to aged 1 half-life sources, demonstrate the importance of accounting for the radiobiological effects of dose protraction. With fresh sources RSBT is significantly superior to conventional HDR-BT in both dose escalation and urethra sparing. With aged 1 half-life sources RSBT is still superior to conventional HDR-BT but the magnitude of the benefit is reduced. As sources age the increasing treatment times required for RSBT become an important clinical consideration. Although treatment times with ^{153}Gd -based RSBT are undesirable, the impact on clinical workflow would be less pronounced than expected. The dose rate of the ^{153}Gd source (7.8 Gy per hour) qualifies as medium-dose-rate brachytherapy treatment (2–12 Gy per hour) meaning that physical presence restrictions on authorized users (physician and medical physicist) are relaxed compared to high-dose-rate brachytherapy. Although the RSBT treatment times are longer than for HDR-BT, the relaxed physical presence restrictions for RSBT would actually reduce the time the physician and physicist would need to be physically present for the delivery relative to HDR-BT.

With extended treatment times, if the physical dose prescription does not increase to adjust for dose protraction then a decreased biological effective dose is given. If Gd_2O_3 sources could be manufactured with higher specific activity, treatment times could be reduced and the magnitude of the benefits from RSBT would be less affected by source aging. However, to achieve treatment times of less than one hour with RSBT would require a specific activity of 12.21 TBq of ^{153}Gd per gram of Gd_2O_3 , or about 5 times the current specific activity. Another option for reducing treatment times is the use of different radioisotopes for the RSBT source, most notably ^{169}Yb . The use of ^{169}Yb in a shielded source has been

demonstrated in cervical cancer brachytherapy [39] and the authors are currently conducting an analysis on ^{169}Yb -based RSBT for prostate cancer treatment.

V. CONCLUSIONS

RSBT can increase PTV EQD_{90%} or decrease urethral $D_{10\%}$ relative to HDR-BT at the cost of increased treatment time. Source aging reduces RSBT benefit, but RSBT remains theoretically superior to HDR-BT by >20% after one-half-life has elapsed.

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A 26-patient treatment planning study comparing rotating shield brachytherapy (RSBT) to conventional high-dose-rate brachytherapy (HDR-BT) for dose escalation, simulating monotherapy, and urethra sparing, simulating boost therapy. The radiobiological effects of dose protraction and source age were accounted for. RSBT can increase PTV EQD_{90%} or decrease urethral $D_{10\%}$ relative to HDR-BT at the cost of increased treatment time. Source aging reduces RSBT benefit, but RSBT remains theoretically superior to HDR-BT by >20% after one-half-life has elapsed.

Figure 1:

(a) Dose distributions for a representative patient. Dose is normalized to effective prescription dose in units of physical dose. **(b)** Dose-volume histograms for the same representative patient. Solid lines are for HDR-BT while the dotted lines are for RSBT.

Table I:

Patients with prostate volumes closest to or corresponding with the PTV volume a) minimum, b) mean – 1 standard deviation, c) mean, d) mean + 1 standard deviation, e) maximum.

Variation in patient anatomy with respect to PTV volume					
Vol (cc)	a) Minimum	b) Mean – 1 SD	c) Mean	d) Mean + 1 SD	e) Maximum
Prostate	39.9	47.3	65.9	76.2	89.3
Urethra	1.4	2.0	1.8	2.2	2.2
Bladder	25.3	33.1	62.0	45.8	42.7
Rectum	25.0	50.4	48.3	46.3	36.9

PTV:
Red
Urethra:
Purple
Bladder:
Yellow
Rectum:
Brown

Table II:

Optimization parameters for RSBT and HDR-BT in the dose escalation plan and the urethra sparing plan. N/A means not applicable.

Dose Escalation							
Tissue	β_k^+	d_k^+	β_k^-	d_k^-	β_k^{V+}	d_k^{V+}	V_k^+
PTV	N/A	N/A	1000	120%	0	N/A	N/A
Urethra	20	45%	0	N/A	0	N/A	N/A
Bladder	20	50%	0	N/A	0	N/A	N/A
Rectum	20	20%	0	N/A	0	N/A	N/A

Urethra Sparing							
Tissue	β_k^+	d_k^+	β_k^-	d_k^-	β_k^{V+}	d_k^{V+}	V_k^+
PTV	N/A	N/A	1000	120%	0	N/A	N/A
Urethra	50	50%	0	N/A	0	N/A	N/A
Bladder	5	50%	0	N/A	20	50%	1%
Rectum	20	20%	0	N/A	20	50%	1%

The parameters $d_k^\pm$, $\beta_k^\pm$ represent the dose threshold and penalty weight, respectively, for overdose (+) and underdose (−), for tissue k . The parameters d_k^{V+} , V_k^+ , β_k^{V+} represent the dose threshold, percent volume threshold, and penalty weight, respectively, for dose-volume overdose (+) for tissue k . The parameter ΔD_k^{V+} represents the difference between the dose planned and desired to V_k^+ in the cumulative dose-volume histogram for tissue k .

Table III:

Treatment planning criteria. Units are physical dose or percentage of physical dose.

Tissue	Criterion	Dose Escalation	Urethra Sparing
		Value	Value
PTV	$D_{90\%}$	>20.9 Gy	16.5 Gy
	$V_{100\%}$	>95%	>95%
	$V_{150\%}$	<40%	<40%
	$V_{200\%}$	<14%	<14%
Urethra	$D_{10\%}$	<20.9 Gy	<16.5 Gy
Bladder	D_{2cc}	<19.2 Gy	<12.9 Gy
Rectum	D_{2cc}	<17.1 Gy	<17.1 Gy

Table IV:

Treatment plan results for RSBT versus HDR-BT.

Tissue	Metric	Modality	Dose Escalation		Urethra Sparing	
			Fresh Sources	Aged 1 Half-Life Sources	Fresh Sources	Aged 1 Half-Life Sources
PTV	EQD ₂ _{90%} (Gy)	HDR-BT	92.0 ± 0.5	90.1 ± 0.8	59.8 ± 0.2	58.8 ± 0.4
		RSBT	131.1 ± 11.0	108.5 ± 9.9	60.1 ± 0.3	59.0 ± 0.5
	Mean <i>G</i> value	HDR-BT	0.977 ± 0.004	0.956 ± 0.007	0.982 ± 0.003	0.964 ± 0.006
		RSBT	0.748 ± 0.032	0.609 ± 0.040	0.831 ± 0.025	0.716 ± 0.036
	<i>D</i> _{90%} (Gy)	HDR-BT	20.9 ± 0.0	20.9 ± 0.0	16.5 ± 0.0	16.5 ± 0.0
		RSBT	24.9 ± 1.1	22.8 ± 2.0	16.4 ± 0.0	16.3 ± 0.0
	<i>V</i> ₁₀₀ (%)	HDR-BT	98.2 ± 0.6	98.1 ± 0.7	97.9 ± 0.8	97.8 ± 0.8
		RSBT	99.8 ± 0.2	99.0 ± 0.9	96.0 ± 0.4	96.0 ± 0.5
	<i>V</i> ₁₅₀ (%)	HDR-BT	31.4 ± 3.9	31.7 ± 3.9	31.8 ± 4.0	31.9 ± 4.1
		RSBT	40.5 ± 4.9	40.9 ± 4.4	39.11 ± 5.6	39.4 ± 5.3
	<i>V</i> ₂₀₀ (%)	HDR-BT	10.3 ± 2.2	10.4 ± 2.2	10.3 ± 2.0	10.4 ± 2.1
		RSBT	9.57 ± 1.7	10.3 ± 1.6	10.1 ± 2.1	10.5 ± 1.9
Urethra	<i>D</i> _{10%} (Gy)	HDR-BT	19.9 ± 0.4	19.9 ± 0.4	15.6 ± 0.3	15.6 ± 0.3
		RSBT	19.9 ± 0.4	19.9 ± 0.4	11.6 ± 0.4	12.5 ± 0.6
Bladder	<i>D</i> _{2cc} (Gy)	HDR-BT	12.7 ± 1.5	12.7 ± 1.5	10.1 ± 1.2	10.1 ± 1.2
		RSBT	15.5 ± 1.9	15.5 ± 1.9	9.6 ± 1.1	10.4 ± 1.3
Rectum	<i>D</i> _{2cc} (Gy)	HDR-BT	5.8 ± 0.8	5.8 ± 0.8	4.6 ± 0.7	4.6 ± 0.7
		RSBT	8.6 ± 1.1	8.6 ± 1.1	5.5 ± 0.7	5.9 ± 0.8
Treatment Time (mins)		HDR-BT	15.0 ± 2.1	30.5 ± 4.2	12.0 ± 1.7	23.9 ± 3.3
		RSBT	217.0 ± 29.0	433.9 ± 57.9	133.6 ± 16.5	267.2 ± 32.9

Table V:

Treatment planning metrics used to compare HDR-BT with RSBT.

Dose Escalation				
Tissue	Metric	Modality	Fresh Sources	Aged 1 Half-Life Sources
PTV	EQD2 _{90%} (Gy)	HDR-BT	92.0 ± 0.5	90.1 ± 0.8
		RSBT	131.1 ± 11.0	108.5 ± 9.9
		% Difference	+42.5 ± 8.4%	+20.5 ± 9.1%
		<i>p</i> -value	<0.0001	<0.0001
	<i>D</i> _{90%} (Gy)	HDR-BT	20.9 ± 0.0	20.9 ± 0.0
		RSBT	24.9 ± 1.1	22.8 ± 2.0
		% Difference	+19.1 ± 4.4%	+9.1 ± 8.7%
		<i>p</i> -value	<0.0001	<0.0001
Urethra Sparing				
Urethra	D _{10%} (Gy)	HDR-BT	15.6 ± 0.3	15.6 ± 0.3
		RSBT	11.5 ± 0.4	12.4 ± 0.6
		% Difference	-26.0 ± 3.5%	-20.2 ± 4.8%
		<i>p</i> -value	<0.0001	<0.0001

Table VI:

Total number of patients and corresponding percentage who met treatment planning criteria requirements. A total of 26 patients were included. N/A means not applicable.

N = 26 (%)			Dose Escalation			Urethra Sparing		
Tissue	Criterion	Value	Modality	Fresh Sources	Aged 1 Half-Life Sources	Fresh Sources	Aged 1 Half-Life Sources	
PTV	$D_{90\%}$	100%	HDR-BT	26 (100)	26 (100)	26 (100)	26 (100)	
			RSBT	26 (100)	26 (100)	26 (100)	26 (100)	
	$V_{100\%}$	>95%	HDR-BT	26 (100)	26 (100)	26 (100)	26 (100)	
			RSBT	26 (100)	26 (100)	22 (85)	20 (77)	
	$V_{150\%}$	<40%	HDR-BT	25 (96)	25 (96)	25 (96)	25 (96)	
			RSBT	19 (73)	16 (62)	20 (77)	20 (77)	
	$V_{200\%}$	<14%	HDR-BT	24 (92)	24 (92)	25 (96)	25 (96)	
			RSBT	25 (96)	25 (96)	25 (96)	25 (96)	
	Urethra	$D_{10\%}$	<110%	HDR-BT	26 (100)	26 (100)	26 (100)	26 (100)
			RSBT	26 (100)	26 (100)	26 (100)	26 (100)	
Bladder	D_{2cc}	<19.2 Gy	HDR-BT	26 (100)	26 (100)	N/A	N/A	
			RSBT	26 (100)	26 (100)	N/A	N/A	
		<12.9 Gy	HDR-BT	N/A	N/A	25 (96)	25 (96)	
			RSBT	N/A	N/A	26 (100)	25 (96)	
Rectum	D_{2cc}	<17.1 Gy	HDR-BT	26 (100)	26 (100)	26 (100)	26 (100)	
			RSBT	26 (100)	26 (100)	26 (100)	26 (100)	